PRINCIPLES OF
GUIDED
MISSILE
DESIGN

A new series
edited by
GRAYSON MERRILL
Captain, USN (ret.)

MISSILE ENGINEERING HANDBOOK

By C. W. BESSERER
SENIOR TECHNICAL STAFF, SPACE TECHNOLOGY LABORATORIES
A DIVISION OF THE RAMO-WOOLDRIDGE CORPORATION

Important handbook data and a glossary of guided missile and space flight terms — useful for reference, for preliminary design, parametric studies and student instruction by all practitioners in the field.

D. VAN NOSTRAND COMPANY, INC.

THE guided missile and space flight practitioner will find here the first unclassified complete handbook in his field. Preliminary designs and parametric studies important in weapon system analysis can be made from these equations, formulas, graphs and tables. They have been selected and conveniently arranged by an experienced author currently working on ballistic missiles. Also supplied is an extensive glossary of guided missile and space flight terms. The Handbook will be particularly helpful to those whose "need-to-know" does not entitle access to classified data.

The data are generally self-explanatory but, in some cases, are presented without instructions for application or qualifications as to tolerances or other limitations. Although suitable for preliminary design, comparative analysis and problem solution by students, they should be checked against data supplied by manufacturers in an actual design case. The reader is presumed to have a knowledge of guided missile practice equivalent to that given in other volumes of the parent series "Principles of Guided Missile Design."

The glossary of terms is authoritative and complete, even as to terms only related to the guided missile and space flight art. Amplifying explanation is given for selected terms. Newcomers to guided missiles will find it especially useful and valuable in their work.

In 1957 the American Rocket Society honored the parent series with its G. Edward Pendray award for rocket literature. This fourth and latest volume maintains the standards of its predecessors, an essential desk-side companion for students, engineers and service officers who devote their energies to the ever-expanding field of guided missiles and space flight.

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PRINCIPLES OF
GUIDED MISSILE DESIGN

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GRAYSON MERRILL, CAPTAIN, U.S.N. (Ret.)

General Manager, Guided Missiles Division, Fairchild Engine and Airplane Corporation

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PRINCIPLES OF

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GRAYSON MERRILL, CAPTAIN, U.S.N. (Ret.)

C. W. BESSERER

Senior Technical Staff
Space Technology Laboratories
The Ramo-Wooldridge Corporation

MISSILE ENGINEERING HANDBOOK

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PREFACE

"Missile Engineering Handbook" is the fourth volume in the series entitled PRINCIPLES OF GUIDED MISSILE DESIGN. The purpose of the series as a whole is to give a basis for instruction to graduate students, engineers and technical officers of the armed services so that they can become well grounded in the technology of guided missiles and space flight. Other titles in the series are "Guidance"; "Aerodynamics, Propulsion, Structures and Design Practice"; "Operations Research, Armament, and Launching"; "Space Flight"; "Systems Engineering"; "Range Testing"; "Airborne Radar"; and "Automatic Flight Controls."

This "Missile Engineering Handbook" is intended as a convenient compendium of the design data which appear in the main series as well as in other unclassified literature. The appended glossary of guided missile terms should be a boon to all those who are called upon to have a working vocabulary in this rapidly developing field. The handbook should be particularly useful to those who wish to make preliminary designs or parametric studies but who do not possess the "need-to-know" entrée to classified literature.

Criticisms and constructive suggestions are invited. By this means and by keeping abreast of the state of the art we hope to make timely revisions to this volume.

Grateful acknowledgment is made to the many authors and publishers who kindly granted permission for the use of their material and to the Department of Defense whose helpful cooperation made possible a meaningful text without violation of security.

The opinions or assertions contained herein are the private ones of the authors and the editor and are not to be construed as official or reflecting the views of any government agency or department.

Wyandanch, L. I., N. Y.
February 1958

GRAYSON MERRILL
Editor

FOREWORD

It is the purpose of this book to provide information which will be useful to engineers, technicians and supporting personnel working in the general field of guided missiles and space flight. The tables, graphs, and equations are largely self-explanatory, but a knowledge of their methods and limitations of application is expected. Such knowledge is to be had from other volumes of the parent series.

The tables and graphs give nominal values, in most cases without specifying tolerances or probable band widths. Final design data and material properties should be obtained from the supplier. Values given in this handbook should be adequate, however, for preliminary or comparative design.

The book is organized into ten sections, the first nine of which comprise design data. The tenth section is a glossary of guided missile terms with some additional terms of a general nature.

Every attempt has been made in the glossary to define terms on an authoritative basis. There will be disagreement on definitions; but if some degree of standardization of terminology is accomplished, or if a better understanding between technical disciplines can result, at least a part of our objective will have been attained. The writer takes full responsibility for inaccuracies or controversial nomenclature or definitions.

It is *not* the intent of this volume to replace conventional engineering handbooks (which are readily available and to be found on most bookshelves). Rather, this handbook is a collection of information observed at first hand to be generally useful to those people engaged in the missile field, especially in the development, design, and test phases. As such, it is somewhat subject to individual experiences and preferences.

Most sincere thanks are due my colleagues at the Ramo-Wooldridge Corporation, and elsewhere in the field of guided missiles, for their suggestions, reviews, and comments. Particular appreciation is due R. R. Irwin for his careful review of the manuscript; and to the many secretaries who worked on the several drafts. Captain Grayson Merrill, USN (Ret.) contributed important suggestions, comments and guidance which are most appreciated. My wife, Hazel, has given up much personal and family routine in order to contribute in a major way to the preparation and review of the manuscript, particularly as it concerned the glossary.

Los Angeles, California
February 1958

C. W. BESSERER

ACKNOWLEDGMENTS

In the compilation of the data sections and glossary of this book, the following publications were broadly used as source material. Where material was used substantially in its original form in the preparation of diagrams, charts, or tables, these figures are listed below the source. In addition to the following, credits to other sources used will be found on the pages where the figures appear in the book. Grateful thanks are extended to all for permission to use material from their publications.

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SECTION 1—GENERAL DATA

FIGURE 1.1 SOME CHARACTERISTICS AND FEATURES OF U.S. GUIDED MISSILES*

Nomenclature				Basic Data			Physical Data				Performance		Status as of Jan. '58				Remarks
Category	Name	Designation	Cognizant Service	Prime Contractor or Manufacturer	Powerplant Type and Manufacturer	Guidance Type and Manufacturer	Weight At Take Off	Length, Less Booster Ft.	Body Diameter, Ft.	Span of Wings or Fins, Ft.	Approximate Maximum Range, Mi.	Approximate Maximum Mach Number	Research	Development	Production	Service Use	
I(A) Air-to-Air	Falcon	GAR-1 GAR-2A	USAF	Hughes	1 Thiokol spr	Radar Infrared	110	6				su	x	x	x	x	Armament for Convair F-102
	Genie(Ding Dong) (High Card)	MB-1	USAF	Douglas	1 A-G spr	Unguided						su			x	x	Nuclear warhead
	Sidewinder	AAM-N-7	BuOrd	Philco	1 ABL spr	Infrared homing (Philco, G.E.)	155	9	4.5						x	x	50,000 ft. alt.
	Sparrow 1	AAM-N-2	BuAer	Sperry/ Douglas	1 A-G spr	Beam Rider (Sperry)	300	12.5				3				x	Phased out
	Sparrow 2	XAAM-N-3	BuAer	Douglas		Radar								x			Experimental
	Sparrow 3	XAAM-N-4	BuAer	Raytheon		Radar (Raytheon)	350	12			6			x	x		
II(A) Air-to-Surface	Bull Pup	XASM-N-7	BuAer	Martin	1 A-G spr	Optical (Martin)	540	11						x			Canard Airframe
	Dove	ASM-N-4 & 5	BuAer	East. Kodak		Optical (East. Kodak)									x		
	Rascal	GAM-63	USAF	Bell	3 Bell lpr	Command (Bell)		32	48"		100	1.5			x	x	B 47; Armament
II(B) Air-to-Underwater	Petrel	AUM-N-2	BuOrd	Fairchild	1 J44 tj	Radar	3,800	24		13		0.7			x	x	Launched from Patrol Aircraft - Phased out

III Surface-to-Air	Bomarc	IM-99	USAF	Boeing	2 Mar. rj. & 1A-G spr booster	Command & Radar	15,000	47		18					x		60,000' alt. capability; nuclear warhead
	Hawk		Army-Ord.	Raytheon/ Northrup	1 Thiokol spr	Radar homing		17	14"						x		Low angle anti-aircraft coverage
	Nike I - Ajax	SAM-A-7	Army-Ord.	West.Elec./ Douglas	1 A-G lpr; AG spr booster	Radar Command (West. Elec.)	1,000	20	1		20	2			x	x	Conus Defense
	Nike B - Hercules		Army-Ord.	West.Elec./ Douglas	1 A-G spr; 4AG spr booster	Radar Command (West. Elec.)		27						x			Nuclear warhead
	Nike - Zeus		Army-Ord.	BTL/ Douglas									x	x			Anti-ICBM
	Talos	XSAM-N-6; IM-70	BuOrd & Army Ord.	Bendix M/ McDonnell	Bx/McD rj; ABL spr booster	Radar	3,000	20	30"		25			x	x		One version carries nuclear warhead. APL/JHU Devel. Cruiser Defense; Land Defense (RCA Respon.)
	Tartar		BuOrd	Convair	1 ABL spr	Beam Rider (Philco; BxP)					20			x	x		Destroyer Anti-aircraft DDG Class
	Terrier 1	SAM-N-7	BuOrd	Convair	1 ABL spr ABL spr booster	Beam Rider (BxP)	3,000	15							x	x	50,000' ceiling
	Wizard		USAF	Convair/ RCA									x				Anti-ICBM
IV(A) Surface-to-Surface (Short Range)	Dart		Army-Ord.	ADC/CW; UB	1 GC spr										x		Anti-tank
	Honest John		Army-Ord.	Douglas/ Emerson	1 Herc. spr	Unguided									x	x	Long-range artillery; nuclear warhead
	Lacrosse		Army-Ord.	Martin	1 Thiokol spr	Command (Martin)									x		CAL Development; close support missile
	Little John		Army-Ord.	Douglas/ Emerson	1 Herc. spr	Unguided								x			Short-range Honest John
IV(B) Surface-to-Surface (Long Range)	Atlas	ICBM-XSM-65 (WS 107A-1)	USAF	Convair	NAA lpr	Radar					5,500	10+	x	x			Intercontinental ballistic missile; nuclear WH; G.E. Nose Cone
	Corporal II	XSSM-A-17	Army-Ord.	Firestone/ Gilfillan	1 JPL lpr	Radar					75	3			x	x	Developed at JPL; nuclear warhead; ballistic trajectory

FIGURE 1.1 SOME CHARACTERISTICS AND FEATURES OF U.S. GUIDED MISSILES* (Cont.)

Nomenclature				Basic Data			Physical Data				Performance		Status as of Jan. '58				Remarks
Category	Name	Designation	Cognizant Service	Prime Contractor or Manufacturer	Powerplant Type and Manufacturer	Guidance Type and Manufacturer	Weight At Take Off	Length, Less Booster Ft.	Body Diameter, Ft.	Span of Wings or Fins, Ft.	Approximate Maximum Range, Mi.	Approximate Maximum Mach Number	Research	Development	Production	Service Use	
IV(B) Surface-to-Surface (Long Range) (cont.)	Jupiter	IRBM	Army-Ord.	Chrysler	1 lpr NAA						1,500		x	x			Intermediate range ballistic missile; nuclear warhead
	Matador	TM 61 A,C,D	USAF	Martin	1 All. J33-A-37 tj; 1 Thiokol spr	Ground controlled		39.5		28.8	600	0.9			x	x	35,000' alt. capability; nuclear warhead
	Mace	TM76A(61B)	USAF	Martin	tj; spr	Self contained					600	0.9		x	x	x	40,000' alt. capability
	Navaho	XSM-64	USAF	No.Amer.	2 Wr.rj;NAA lpr booster	Inertial (NAA)					5,500	3		x			Three versions planned; program cancelled
	Pershing		Army-Ord.		spr									x			Replacement for Redstone
	Polaris	IRBM	BuOrd	Lockheed	A-G spr	Inertial (G.E.)					1,500		x	x			Fleet ballistic missile; nuclear WH
	Redstone		Army-Ord.	Chrysler	1 NAA lpr						175			x	x	x	
	Regulus I	SSM-N-8	BuAer	Chance Vought	1 All. J33-18A tj; 2 A-G spr	Inertial (Sperry)					500	0.9			x	x	
	Regulus II		BuAer	Chance Vought	tj; 2 spr	Self-contained	14,000	30	4.5		1,000	2		x	x		Nuclear WH; 50,000 ft. altitude

	Sergeant		Army-Ord.	JPL/ Sperry	1 Thiokol spr			20						x	x		Corporal replacement; ballistic trajectory
	Snark	SM-62	USAF	Northrup	1 P & W J-57 tj; 2 A-G spr	Self-contained (Northrup)					5,000				x	x	Nuclear WH
	Thor	IRBM-XSM-75 (WS 315A)	USAF	Douglas	1 NAA lpr	Inertial (A C Spark Plug)					1,500	5+		x	x		Intermediate Range Ballistic missile, nuclear WH; G.E. Nose Cone
	Titan	ICBM-XSM-68 (WS 107A-2)	USAF	Martin	A-G lpr	Self-contained					5,500	15+	x	x			Intercontinental ballistic missile; nuclear WH; AVCO Nose Cone
	Triton		BuOrd	McDonnell	McD rj; ABL spr booster							3	x	x			APL/JHU Devel.; Program suspended
V Research	Aerobee	V-A-1A	USAF; Navy Signal Corp.	Aerojet/ Cooper Development	1 A-G lpr		1,140	20.0	1.3	5.2		4.8			x		370,000' ceiling; 3 fins
	Aerobee-Hi	AJ 11-6 AJ 11-18	USAF; NAVY	Aerojet	1 A-G lpr		1,310	31	1.3	5.2		6.5			x		820,000' ceiling; 3 fins-payload 130#
	ASP			GC	1 GC spr		245	12	0.5			5		x			175,000' ceiling; 3 fins
	Explorer I (1958 Alpha)	Jupiter "C"	Army-Ord.		1 lpr; 3 stages spr								x				Satellite (31 lb.)
	HTV-Hypersonic Test Vehicle		USAF	ADC	spr												Used for Aerothermodyno. research
	Terrapin			Univ.of Md.										x			
	Oriole			Univ.of Md.										x			120 mile alt. max.
	Vanguard		BuAer	Martin	1st Stage GE lpr, 2nd Stage A-G lpr, 3rd Stage GC spr		2,200	72'	3.9								Earth Satellite; Payload 21.5#
	Viking		NRL	Martin	1 RMI lpr									x	x		14 built-alt. test vehicle
	Wasp				1 GC spr												Adopted from Loki 110,000 - 150,000 Ionsphere research
	X-7		USAF	Lockheed	Mar rj							3	x				Exp. test bed
	X-17		USAF	Lockheed	3 Stage; Thiokol spr		12,000	40									Re-entry test vehicle; Payload 75#

Note: Footnotes for Figure 1.1 on following page.

FIGURE 1.1 SOME CHARACTERISTICS AND FEATURES OF U.S. GUIDED MISSILES (cont.)

ADC - Aerophysics Development Corp.; Curtiss Wright
A-G - Aerojet-General Corp.
All - Allison Division
APL/JHU - Johns Hopkins Univ., Applied Physics Lab.
Army-Ord - Army Ordnance
BM - Bendix-Mishawaka
BP - Bendix-Pacific
BTL - Bell Telephone Laboratories
BuAer - Navy Bureau of Aeronautics
BuOrd - Navy Bureau of Ordnance
BUR - Burroughs
CAL - Cornell Aeronautical Laboratory
Con - Continental Motors Corporation
CV - Chance Vought
CW - Curtiss Wright
Emer - Emerson
Fair - Fairchild-Engine Division
Ford - Ford Instrument Co.
GC - Grand Central Rocket Co.
G.E. - General Electric
Herc - Hercules Powder Co.
JPL - Jet Propulsion Lab; Cal. Tech.
Lyc - Lycoming Div. of AVCO
Mar - Marquardt Aircraft Co.
McC - McCulloch Motors
NAA - North American Aviation, Inc.
NRL - Naval Research Lab.
P & W - Pratt & Whitney Aircraft Div.
RMI - Reaction Motors, Inc.
RRU - Remington-Rand Univac
SigCor - Signal Corps, Dept. of Army
Sperry - Sperry Gyroscope Co.
Thiokol - Thiokol Chem. Corp.
UB - Utica-Bend
USAF - United States Air Force
Wstghse - Westinghouse Electric

lpr - Liquid Propellant Rocket
rj - Ramjet
spr - Solid Propellant Rocket
su - Supersonic
tj - Turbojet
* - Obsolete Program or Programs Cancelled Prior to 1957 are not included.

FIGURE 1.2 CONVERSION TABLES

AREA

To Convert From	To	Multiply by
Circular mils	Sq centimeters	5.067×10^{-6}
Circular mils	Sq inches	7.854×10^{-7}
Circular mils	Sq mils	0.7854
Sq centimeters	Sq inches	0.1550
Sq feet	Sq centimeters	929.0
Sq feet	Sq inches	144
Sq feet	Sq meters	0.0929
Sq inches	Sq centimeters	6.452
Sq inches	Sq feet	0.006944
Sq inches	Circular mils	1.273×10^{6}
Sq inches	Sq millimeters	645.2
Sq inches	Sq mils	10^{6}
Sq millimeters	Circular mils	1973
Sq millimeters	Sq mils	1550
Sq mils	Circular mils	1.273
Sq yards	Sq feet	9
Sq yard	Sq inches	1296

LENGTH

Centimeters	Inches	0.3937
Centimeters	Meters	0.01
Centimeters	Mils	393.7
Feet	Meters	0.3048
Inches	Feet	0.0833
Inches	Millimeters	25.40

FIGURE 1.2 CONVERSION TABLES (cont.)

LENGTH (cont.)

To Convert From	To	Multiply by
Inches	Mils	1000
Kilometers	Feet	3281
Kilometers	Miles	0.6214
Kilometers	Nautical miles	0.5400
Kilometers	Yards	1094
Leagues	Miles (approx.)	3
Light years	Miles	588×10^{12}
Meters	Feet	3.281
Meters	Inches	39.37
Meters	Yards	1.094
Miles	Feet	5280
Miles	Meters	1609
Miles	Nautical miles	0.8690
Miles	Yards	1760
Miles (nautical)	Feet	6076.1033
Miles (nautical)	Meters	1851.906
Miles (nautical)	Miles (statute)	1.1507
Millimeters	Inches	0.03937
Millimeters	Mils	39.37
Mils	Inches	0.001
Yards	Meters	0.9144

ANGULAR MEASURE

Degrees (angle)	Radians	0.017453
Mils	Minutes	3.375
Revolutions	Radians	$6.283(2\pi)$
Radians	Degrees	57.2958

VOLUME

Cubic centimeters	Cubic inches	0.06102
Cubic centimeters	Liters	0.001
Cubic feet	Cubic centimeters	28317
Cubic feet	Cubic inches	1728
Cubic feet	Cubic years	1/27
Cubic feet	Gallons	7.481
Cubic feet	Liters	28.32
Cubic feet	Quarts (liquid)	29.92
Cubic inches	Cubic centimeters	16.3872
Cubic inches	Cubic feet	5.787×10^{-4}
Cubic inches	Cubic gallons	4.3290×10^{-3}
Cubic inches	Cubic meters	1.639×10^{-5}
Cubic inches	Liters	1.6389×10^{-2}
Cubic meters	Cubic feet	35.31

FIGURE 1.2 CONVERSION TABLES (cont.)

VOLUME (cont.)

To Convert From	To	Multiply by
Cubic meters	Gallons	264.2
Cubic meters	Liters	1000
Cubic meters	Cubic yards	1.308
Cubic yards	Cubic feet	27
Cubic yards	Cubic inches	46656
Cubic yards	Gallons	202.0
Gallons	Cubic feet	0.1337
Gallons	Cubic inches	231
Gallons	Liters	3.785
Gallons	Cubic meters	3.785×10^{-3}
Gallons	Ounces (U.S. Fluid)	128
Gallons	Lb. of water at 60°F	8.337
Liters	Cubic feet	0.03532
Liters	Cubic inches	61.03
Liters	Gallons	0.2642
Liters	Cubic centimeters	1000
Liters	Pints (U.S.)	2.113
Ounces (fluid)	Quarts	0.03125
Pints	Quarts	1/2
Quarts (liquid)	Liters	0.9463
Quarts (liquid)	Pints (liquid)	2
Quarts (liquid)	Quarts (dry)	0.8594

WEIGHT OR FORCE

Centigrams	Grams	0.01
Decigrams	Grams	0.1
Dynes	Grams	0.00102
Dynes	Pounds	2.248×10^{-6}
Grains	Pounds (avoird)	1.429×10^{-4}
Grams	Ounces	0.0353
Grams	Dynes	980.665
Grams	Grains	15.432
Grams	Pounds	2.2046×10^{-3}
Grams	Poundals	0.0709
Kilograms	Pounds	2.205
Newtons	Dynes	10^5
Newtons	Kilograms	0.1020
Newtons	Poundals	7.233
Newtons	Pounds (avoird)	0.2248
Ounces	Grams	28.349
Ounces	Pounds	0.0625
Poundals	Pounds	0.03108
Poundals	Dynes	1.383×10^4
Pounds	Grams	453.6
Pounds	Tons (long)	4.46×10^{-4}

FIGURE 1.2 CONVERSION TABLES (cont.)

WEIGHT OR FORCE (cont.)

To Convert From	To	Multiply by
Pounds	Tons (metric)	4.54×10^{-4}
Pounds	Tons (short)	5×10^{-4}
Pounds of water	Cubic feet	0.0160
Pounds of water	Gallons	0.1198
Slugs	Pounds	32.174 (gravity)
Tons (long)	Tons (short)	1.12
Tons (metric)	Tons (short)	1.102
Tons (short)	Kilograms	907.2
Tons (short)	Pounds	2000
Tons (U.S. Shipping)	Cubic feet	40

PRESSURE

Atmospheres	Cm of Hg (O°C)	76
Atmospheres	Inches of Hg (32°F)	29.9213
Atmospheres	Feet of water at 59°	33.9291
Atmospheres	Inches of mercury	29.92
Atmospheres	Millibars	1013.25
Atmospheres	Millimeters of mercury	760
Atmospheres	Pounds per square foot	2116.22
Atmospheres	Pounds per square inch	14.696
Atmospheres	Kilograms per square meter	1.033×10^4
Atmospheres	Newtons per square meter	1.0133×10^5
Bars	Atmospheres	0.98692
Bars	Pounds per square inch	14.504
Cm of Hg at 32°F	Atmospheres	0.013158
Cm of Hg at 32°F	Feet of water at 39°F	0.44604
Cm of Hg at 32°F	Pounds per square foot	27.845
Cm of Hg at 32°F	Pounds per square inch	0.19337
Feet of water at 59°	Atmospheres	0.02947
Feet of water at 59°	Inches of Hg at 32°F	0.8819
Feet of water at 59°	Millibars	29.89
Feet of water at 59°	Pounds per square foot	62.372
Feet of water at 59°	Pounds per square inch	0.4331
Feet of water at 59°	Millimeters of mercury	22.40
Grams per sq cm	Pounds per square foot	2.048
Inches of Hg (32°F)	Atmospheres	0.03342
Inches of Hg (32°F)	Pounds per square inch	0.4912
Inches of mercury at 32°F	Feet of water at 59°F	1.134
Inches of mercury at 32°F	Inches of water at 59°F	13.607
Inches of mercury at 32°F	Millimeters of mercury	25.40
Inches of mercury at 32°F	Millibars	33.864
Inches of mercury at 32°F	Atmospheres	0.0334
Inches of mercury at 32°F	Pounds per square foot	70.727
Inches of mercury at 32°F	Pounds per square inch	0.4912
Inches of water	Pounds per square inch	0.0361

FIGURE 1.2 CONVERSION TABLES (cont.)

PRESSURE (cont.)

To Convert From	To	Multiply by
Inches of water	Inches of mercury	0.0736
Inches of water	Millimeters of mercury	1.867
Inches of water at 39°F	Kilograms per square meter	25.40
Inches of water at 39°F	Ounces per square inch	0.5782
Inches of water at 59°F	Atmospheres	0.002456
Inches of water at 59°F	Inches of mercury at 32°F	0.07349
Inches of water at 59°F	Millibars	2.491
Inches of water at 59°F	Pounds per square foot	5.198
Kg per square meter	Pounds per square foot	0.2048
Millibars	Atmospheres	9.869×10^{-4}
Millibars	Feet of water	0.03346
Millibars	Inches of mercury	0.02953
Millibars	Inches of water	0.4015
Millibars	Pounds per square foot	2.0886
Millibars	Pounds per square inch	0.0145
Ounces per square inch	Grams per square cm	4.394
Ounces per square inch	Inches of Hg (32°F)	0.1273
Ounces per square inch	Pounds per square inch	0.0625
Pounds per square foot	Pounds per square inch	0.006944
Pounds per square foot	Kg per square meter	4.882
Pounds per square foot	Atmospheres	0.000472541
Pounds per square foot	Feet of water	0.0160328
Pounds per square foot	Inches of mercury	0.0141389
Pounds per square foot	Inches of water	0.192394
Pounds per square foot	Millibars	0.47880
Pounds per square inch	Pounds per square foot	144
Pounds per square inch	Inches of water	27.70
Pounds per square inch	Inches of mercury	2.036

MASS

Slugs	Pounds	32.16
Grams per cubic centimeter	Pounds per cubic inch	0.03613
Grams per cubic centimeter	Pounds per cubic foot	62.43
Pounds per cubic foot	Kilograms per cubic meter	16.02
Pounds per cubic inch	Pounds per cubic foot	17.28

VOLUME RATE

Cubic feet per minute	Gallons per second	0.1247
Gallons per minute	Cubic feet per second	0.002280

FIGURE 1.2 CONVERSION TABLES (cont.)

POWER

To Convert From	To	Multiply by
Btu (mean) per minute	Horsepower	0.02358
Btu per minute	Foot-pounds per second	12.96
Btu per minute	Watts	17.57
Btu per minute	Kg calories per minute	0.2520
Calories (kg) per minute	Horsepower	0.09356
Foot-pounds per minute	Foot-pounds per second	0.01667
Foot-pounds per minute	Horsepower	3.030×10^{-5}
Foot-pounds per second	Calories (gram) per second	0.3239
Foot-pounds per second	Horsepower	1.818×10^{-3}
Horsepower	Btu (mean) per minute	42.42
Horsepower	Calories (kg) per minute	10.69
Horsepower	Foot-pounds per minute	33,000
Horsepower	Foot-pounds per second	550
Horsepower	Horsepower (metric)	1.014
Horsepower	Watts	745.7
Horsepower	Kilogram meters per second	76.040
Horsepower (metric)	Foot-pounds per second	542.5
Horsepower (metric)	Kilogram meters per second	75
Horsepower (metric)	Kilowatts	0.7355
Horsepower (metric)	Btu per minute	41.83
Horsepower (metric)	Foot-pounds per minute	3.255×10^{4}
Horsepower (metric)	Kg calories per minute	10.54
Horsepower (metric)	Horsepower	0.9863
Horsepower (boiler)	Btu per hour	3.347×10^{4}
Horsepower	Btu per hour	2545.08
Horsepower	Kilowatts	0.7457
Horsepower	Thrust	2.6
Kg calories per minute	Foot-pounds per second	51.43
Kilowatts	Foot-pounds per second	737.6
Kilowatts	Horsepower	1.341
Kilowatts	Btu per second	0.9478
Kilowatts	Kilogram calories per second	0.2388
Thrust (static)	Horsepower	0.385
Watts	Joules per second	1
Watts	Btu per minute	0.05689
Watts	Ergs per second	1×10^{-7}
Watts	Foot-pounds per minute	44.26
Watts	Foot-pounds per second	0.737
Watts	Horsepower	1.341×10^{-3}
Watts	Horsepower (metric)	1.360×10^{-3}
Watts	Kg calories per minute	1.433×10^{-2}

FIGURE 1.2 CONVERSION TABLES (cont.)

WORK

To Convert From	To	Multiply by
Btu	Ergs	1.055×10^{10}
Btu	Joule	1055
Btu	Kilowatt hour	2.93×10^{-4}
Btu	Foot-pounds	778
Btu	Horsepower hours	3.93×10^{-4}
Ergs	Btu (mean)	9.481×10^{-11}
Ergs	Dyne cm.	1.0
Ergs	Foot-pounds	7.376×10^{-8}
Ergs	Joules	1×10^{-7}
Ergs	Horsepower hour	3.72×10^{-12}
Foot-pounds	Horsepower hour	5.050×10^{-7}
Foot-pounds	Kilogram-meters	0.1383
Foot-pounds	Kilowatt hours	3.766×10^{-7}
Foot-pounds	Btu (mean)	1.2854×10^{-3}
Foot-pounds	Joules (abs)	1.35582
Horsepower	Foot-pounds per second	550
Horsepower	Watts per second	746
Horsepower hours	Btu (mean)	2545.08
Horsepower hours	Foot-pounds	1.980×10^{6}
Horsepower hours	Joules	2.686×10^{6}
Horsepower hours	Ergs	2.686×10^{13}
Joules	Kilowatt hours	2.78×10^{-5}
Joules	Ergs	1×10^{7}
Joules	Foot-pounds	0.7373
Joules	Horsepower hours	3.72×10^{-5}
Kilogram calories	Kilogram-meters	426.9
Kilogram calories	Kilowatt hours	1.163×10^{-3}
Kilogram calories	Foot-pounds	3087
Kilogram calories	Horsepower hours	1.56×10^{-3}
Kilogram calories	Kilojoules	4.186
Kilowatts	Foot-pounds per second	737.3
Kilowatt-hours	Btu	3413
Kilowatt-hours	Foot-pounds	2.655×10^{6}
Kilowatt-hours	Joules	3.6×10^{6}
Kilowatt-hours	Kilogram-calories	860
Kilowatt-hours	Kilogram-meters	3.671×10^{5}
Kilowatt-hours	Pounds carbon oxydized	0.235
Kilowatt-hours	Pounds water evaporated from and at 212°F	3.53
Kilowatt-hours	Pounds water raised from 62° to 212°F	22.75
Kilowatt-hours	Horsepower hours	1.34
Watts	Foot-pounds per minute	44.25

FIGURE 1.2 CONVERSION TABLES (cont.)

HEAT

To Convert From	To	Multiply by
Btu	Kilogram-calories	0.2520
Btu (mean per second)	Horsepower	1.4145
Btu per hour	Horsepower hours	3.929×10^{-4}
Btu per hour per square foot per degree F	Kilogram-calories per hour per square meter per degree C	4.88
Btu per hour per square foot per degree F	P.c.u.* per hour per square foot per degree C	1
Btu per hour per square foot per degree F	Gram-calories per second per square centimeter per degree C	1.356×10^{-4}
Btu per hour per square foot per degree F	Watts per square centimeter per degree C	5.68×10^{-4}
Btu per hour per square foot per degree F	Watts per square inch per degree F	2.04×10^{-3}
Btu per hour per square foot per degree F	Horsepower per square foot per degree F	3.93×10^{-4}
Btu per hour per square foot per degree F per foot	Btu per hour per square foot per degree F per inch	12
Btu per hour per square foot per degree F per foot	Kilogram-calories per hour per square meter per degree C per meter	1.49
Btu per hour per square foot per degree F per foot	P.c.u.* per hour per square foot per degree C per inch	12
Btu per hour per square foot per degree F per foot	Gram-calories per second per square centimeter per degree C per centimeter	0.004134
Btu per hour per square foot per degree F per foot	Watts per square centimeter per degree C per centimeter	0.0173
Btu per hour per square foot per degree F per foot	Watts per square inch per degree F per inch	0.0244
Btu per hour per square foot per degree F per foot	Horsepower per square foot per degree F per foot	0.000393
Btu per minute	Foot-pounds per second	12.96
Btu per minute	Horsepower	0.02356
Btu per minute	Watts	17.57
Btu per minute	Kilogram-calories per minute	0.2520
Gram-calories	Btu	3.968×10^{-3}
Horsepower hour	Btu	2545
Horsepower hour	Kilogram-calories	641
Kilowatt hours	Btu	3412
Kilowatt hours	Kilogram-calories	860
Watt-seconds	Gram-calories	0.2389

* One p.c.u. is the heat required to raise the temperature of one pound of water 1°C.

FIGURE 1.2 CONVERSION TABLES (cont.)

LINEAR VELOCITY

To Convert From	To	Multiply by
Centimeters/second	Feet/minute	1.968
Feet/minute	Centimeters/second	0.5080
Feet/minute	Feet/second	0.01667
Feet/minute	Knots	0.009875
Feet/minute	Miles/hour	0.01136
Feet/minute	Centimeters/second	30.48
Feet/second	Kilometers/hour	1.097
Feet/second	Knots	0.5924
Feet/second	Miles/hour	0.6818
Inches/minute	Feet/second	0.001389
Inches/second	Miles/hour	0.05682
Knots	Feet/second	1.688
Knots	Feet/minute	101.268
Knots	Kilometers/hour	1.852
Knots	Nautical miles/hour	1
Knots	Miles/hour	1.151
Knots	Meters/minute	30.865
Meters/minute	Knots	0.03240
Meters/minute	Feet/minute	3.281
Meters/minute	Kilometers/hour	0.06
Miles/hour	Kilometers/minute	0.02682×10^{-2}
Miles/hour	Kilometers/hour	1.609
Miles/hour	Feet/minute	88
Miles/hour	Feet/second	1.467
Miles/hour	Knots	0.8688

ANGULAR RATES

Degrees/hour	Earth's rate	0.06667
Degrees/second	Radians/second	0.017453
Degrees/second	Revolutions/minute	0.1667
Revolutions/minute	Radians/second	0.1047
Radians/second	Revolutions/minute	9.549
Radians/second	Revolutions/second	0.1596

ELECTRICAL QUANTITIES

Amperes	Abamperes	0.1
Ampere-hours	Coulombs	3.600
Ampere-hours	Faradays	0.03731
Ampere per sq cm	Amperes per sq in.	6.452
Ampere turns	Gilberts	1.257
Ampere turns per cm	Ampere turns per inch	2.540
Coulombs	Abcoulombs	0.1
Coulombs	Faradays	1.037×10^{-5}
Faradays	Ampere-hours	26.80

FIGURE 1.2 CONVERSION TABLES (cont.)

ELECTRICAL QUANTITIES (cont.)

To Convert From	To	Multiply by
Farads	Abfarads	10^{-9}
Farads	Microfarads	1×10^{6}
Gausses	Maxwells/sq cm	1
Gausses	Lines/sq in.	6.452
Henries	Abhenries	1×10^{9}
Nepers	Decibels	8.686
Ohm-cm	Circ Mil-Ohms/ft	6.015×10^{6}
Ohm-cm	Ohm-inches	0.3937
Volts	Abvolts	1×10^{8}
Webers per sq meter	Gausses	1×10^{4}

ILLUMINATION

Candles	Lumens/steradian	1
Candles/sq cm	Lamberts	3.1416
Candles/sq in.	Lamberts	0.48695
Candlepower	Lumens	12.566
Foot-candles	Lumens/sq ft	1
Foot-candles	Lux	10.764
Foot-lamberts	Lumens/sq ft	1
Lamberts	Candles/sq ft	295.72
Lamberts	Lumens/sq cm	1
Lamberts	Lumens/sq ft	929.03
Lamberts	Candles/sq cm	0.3183
Lamberts	Candles/sq in.	2.054
Lumens	Watts	0.001496
Lumens/sq cm	Lamberts	1
Lumens/sq ft	Foot-candles	1
Lux	Foot-candles	0.0929

CORROSION-RATE

Grams per square inch per hour	Milligrams per square decimeter per day (mdd.)	372,000
Grams per square meter per year	Milligrams per square decimeter per day (mdd.)	0.0274
Milligrams per square decimeter	Ounces per square foot	0.0003277
Milligrams per square decimeter per day (mdd.)	Grams per square inch per hour	0.00000269
Milligrams per square decimeter per day (mdd.)	Grams per square meter per year	36.5

FIGURE 1.2 CONVERSION TABLES (cont.)

CORROSION-RATE (cont.)

To Convert From	To	Multiply by
Milligrams per square decimeter per day (mdd.)	Pounds per square foot per year	0.00748
Ounces per square foot	Milligrams per square decimeter	3,052
Pounds per square foot per year	Milligrams per square decimeter per day (mdd.)	133.8

VISCOSITY

To Convert From	To	Multiply by
Centipoise gm (mass)/cm sec	Poises	.01
	lb (mass)/sec ft	0.00672
	lb (force) sec/ft^2	0.0000209
	lb (mass)/hr ft	2.42
	Kg (mass)/hr m	3.60
Viscosity in centipoises	Viscosity in poises = gm/sec/cm	0.01
	kg/hr/m	3.60
	lb/sec/ft	0.00672
	lb/hr/ft	2.42
Stokes (cm^2/sec)	Centistokes	100.
	in^2/sec	0.155
	ft^2/sec	0.001076

MISCELLANEOUS

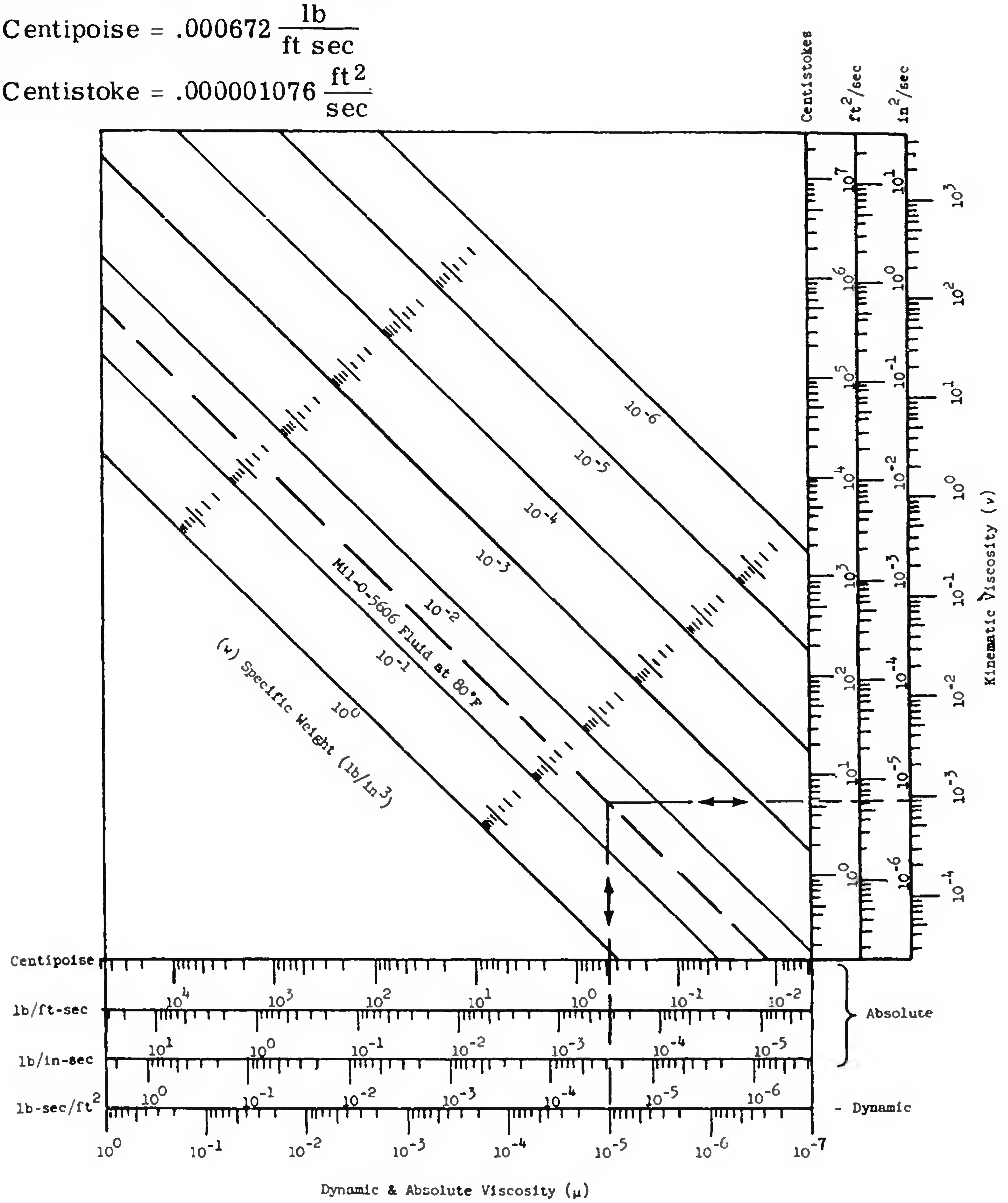
To Convert From	To	Multiply by
$Log_e N$	$Log_{10} N$	0.4343
Grams per centimeter	Pounds per inch	5.60×10^{-3}
Pounds per inch	Kilograms per meter	17.86
Pounds per foot	Kilograms per meter	1.488

FIGURE 1.3 VISCOSITY CONVERSION CHART

General Equations:

1. $\nu w = \mu$
2. μ (Dynamic) x g = μ (Absolute)

   ($g = 32.2\ ft/sec^2 = 386.4\ in/sec^2$)
3. $1\ \text{Centipoise} = .000672 \dfrac{lb}{ft\ sec}$
4. $1\ \text{Centistoke} = .000001076 \dfrac{ft^2}{sec}$

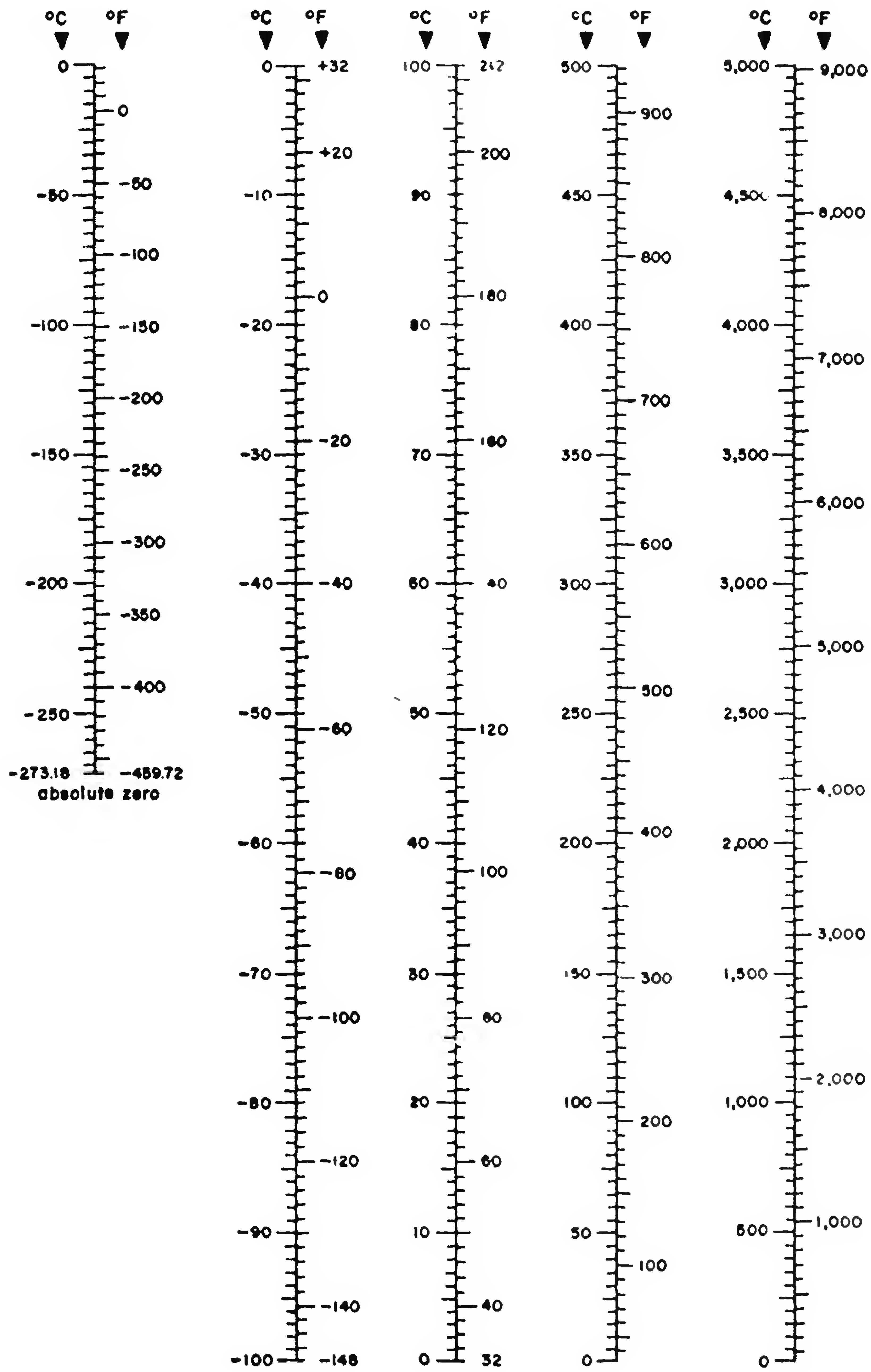


The above conversion chart simplifies determination of any desired set of viscosity units when a particular set of units is given with the specific weight of the fluid (liquid or gas).

Example: To express the viscosity of hydraulic fluid, MIL-0-5606, in sq ft per sec when it is given in 0.49 centipoise with the specific weight at 80F at 0.03 lb per cu inch. Locate (4.9) (10^{-1}) on the centipoise (vertical) scale and draw a horizontal line. Pass a vertical line through the horizontal line at the point of intersection with a line through (3) (10^{-2}) lb per cu inch. Where the vertical line passes through the horizontal scale, read the result of (6) (10^{-6}), or 0.000006 sq ft per second.

FIGURE 1.4 TEMPERATURE CONVERSIONS

Centigrade-to-Fahrenheit Conversion Chart



. Centigrade = $(°F - 32)\frac{5}{9}$

. Fahrenheit = $(°C \times \frac{9}{5}) + 32$

. Kelvin (Centigrade Absolute) = °C + 273.18

. Rankine (Fahrenheit Absolute) = °F + 459.72

FIGURE 1.5 ATOMIC WEIGHTS

(From CHEMICAL ENGINEERING HANDBOOK)

For the sake of completeness all known elements are included in the list. Several of those more recently discovered are represented only by the unstable isotopes. The value in parentheses in the atomic weight column is, in each case, the mass number of the most stable isotope.

Name	Symbol	At. No.	International atomic weight		Valence
			1925	1957	
Actinium	Ac	89	....	227	......
Aluminum	Al	13	26.97	26.98	3
Americium	Am	95	....	(243)	3, 4, 5, 6
Antimony, stibium	Sb	51	121.77	121.76	3, 5
Argon	A	18	39.91	39.944	0
Arsenic	As	33	74.96	74.91	3. 5
Astatine	At	85	....	(211)	1, 3, 5, 7
Barium	Ba	56	137.37	137.36	2
Berkelium	Bk	97	....	(249)	3, 4
Beryllium	Be	4	9.02	9.013	2
Bismuth	Bi	83	209.00	209.00	3, 5
Boron	B	5	10.82	10.82	3
Bromine	Br	35	79.916	79.916	1, 3, 5, 7
Cadmium	Cd	48	112.41	112.41	2
Calcium	Ca	20	40.07	40.08	2
Californium	Cf	98	....	(249)	......
Carbon	C	6	12.000	12.011	2, 4
Cerium	Ce	58	140.25	140.13	3, 4
Cesium	Cs	55	132.81	132.91	1
Chlorine	Cl	17	35.457	35.457	1, 3, 5, 7
Chromium	Cr	24	52.01	52.01	2, 3, 6
Cobalt	Co	27	58.94	58.94	2, 3
Columbium, see Niobium					
Copper	Cu	29	63.57	63.54	1, 2
Curium	Cm	96	....	(245)	3
Dysprosium	Dy	66	162.52	162.51	3
Einsteinium	E	99	....	(254)	......
Erbium	Er	68	167.7	167.27	3
Europium	Eu	63	152.0	152.0	2, 3
Fermium	Fm	100	....	(252)	......
Fluorine	F	9	19.00	19.00	1
Francium	Fr	87	....	(223)	1
Gadolinium	Gd	64	157.26	157.26	3
Gallium	Ga	31	69.72	69.72	2, 3
Germanium	Ge	32	72.60	72.60	4
Gold, aurum	Au	79	197.2	197.0	1, 3
Hafnium	Hf	72	....	178.58	4
Helium	He	2	4.00	4.003	0
Holmium	Ho	67	163.4	164.94	3
Hydrogen	H	1	1.008	1.0080	1
Indium	In	49	114.8	114.82	3
Iodine	I	53	126.932	126.91	1, 3, 5, 7
Iridium	Ir	77	193.1	192.2	3, 4
Iron, ferrum	Fe	26	55.84	55.85	2, 3
Krypton	Kr	36	82.9	83.8	0
Lanthanum	La	57	138.90	138.92	3
Lead, plumbum	Pb	82	207.20	207.21	2, 4
Lithium	Li	3	6.940	6.940	1
Lutetium	Lu	71	175.0	174.99	3
Magnesium	Mg	12	24.32	24.32	2
Manganese	Mn	25	54.93	54.94	2,3,4,6,7

FIGURE 1.5 ATOMIC WEIGHTS (cont.)

Name	Symbol	At. No.	International atomic weight		Valence
			1925	1957	
Mendelevium	Mv	101	....	(256)	......
Mercury, hydragyrum	Hg	80	200.61	200.61	1, 2
Molybdenum	Mo	42	96.0	95.95	3, 4, 6
Neodymium	Nd	60	144.27	144.27	3
Neon	Ne	10	20.2	20.183	0
Neptunium	Np	93	....	(237)	4, 5, 6
Nickel	Ni	28	58.69	58.71	2, 3
Niobium, columbium	Nb	41	93.1	92.91	3, 5
Nitrogen	N	7	14.008	14.008	3, 5
Osmium	Os	76	190.8	190.2	2, 3, 4, 8
Oxygen	O	8	16.000	16.000	2
Palladium	Pd	46	106.7	106.7	2, 4
Phosphorus	P	15	31.027	30.975	3, 5
Platinum	Pt	78	195.23	195.09	2, 4
Plutonium	Pu	94	....	(242)	3, 4, 5, 6
Polonium	Po	84	....	210	......
Potassium, kalium	K	19	39.096	39.100	1
Praseodymium	Pr	59	140.92	140.92	3
Promethium	Pm	61	....	(145)	3
Protactinium	Pa	91	....	231	......
Radium	Ra	88	225.95	226.05	2
Radon	Rn	86	222	222	0
Rhenium	Re	75	....	186.22	......
Rhodium	Rh	45	102.91	102.91	3
Rubidium	Rb	37	85.44	85.48	1
Ruthenium	Ru	44	101.7	101.1	3, 4, 6, 8
Samarium	Sm, Sa	62	150.43	150.35	2, 3
Scandium	Sc	21	45.10	44.96	3
Selenium	Se	34	79.2	78.96	2, 4, 6
Silicon	Si	14	28.06	28.09	4
Silver, argentum	Ag	47	107.880	107.880	1
Sodium, natrium	Na	11	22.997	22.991	1
Strontium	Sr	38	87.63	87.63	2
Sulfur	S	16	32.064	32.066*	2, 4, 6
Tantalum	Ta	73	181.5	180.95	5
Technetium	Tc	43	....	(99)	6, 7
Tellurium	Te	52	127.5	127.61	2, 4, 6
Terbium	Tb	65	159.2	158.93	3
Thallium	Tl	81	204.39	204.39	1, 3
Thorium	Th	90	232.15	232.05	4
Thulium	Tm	69	169.4	168.94	3
Tin, stannum	Sn	50	118.70	118.70	2, 4
Titanium	Ti	22	48.1	47.90	3, 4
Tungsten	W	74	184.0	183.86	6
Uranium	U	92	238.17	238.07	4, 6
Vanadium	V	23	50.96	50.95	3, 5
Xenon	Xe	54	130.2	131.30	0
Ytterbium	Yb	70	173.6	173.04	2, 3
Yttrium	Y	39	88.9	88.92	3
Zinc	Zn	30	65.38	65.38	2
Zirconium	Zr	40	91	91.22	4

*Because of natural variations in the relative abundances of the isotopes of sulfur the atomic weight of this element has a range of $\pm$ 0.003.

FIGURE 1.6 NUMERICAL PREFIXES

Prefix	Meaning	Numerical Value
Micromicro-	One-trillionth	0.000,000,000,001 or 10^{-12}
Millimicro- .	One-billionth	0.000,000,001 . . .or 10^{-9}
Micro-	One-millionth	0.000,001 . . . . . .or 10^{-6}
Milli-	One-thousandth	0.001. . . . . .or 10^{-3}
Centi-	One-hundreth	0.01 . . . . or 10^{-2}
Deci-	One-tenth	0.1 . . . . or 10^{-1}
Deka-	Ten.	10 . . . . or 10
Hecto-.	One hundred . .	100. . . . . or 10^{2}
Kilo-.	One thousand .	1,000. . . . . or 10^{3}
Myria-	Ten thousand .	10,000. . . . . or 10^{4}
Mega-	One million. . .	1,000,000 . . . . . or 10^{6}

FIGURE 1.7 SELECTED PHYSICAL CONSTANTS

Length of seconds pendulum at sea level, lat 45° = 99.356 cm = 39.116 in.

1 mil (angular measure) = 360°/6400 (Army Ordnance)

1 mil (angular measure) = 1/1000 radian (Naval Ordnance)

1 Navy mil = 1.0186 Army mil

1 Angstrom unit A = 3.937×10^{-9} inch = 1×10^{-4} micron = 1×10^{-10}meter

1 Micron = 10^{-4} cm

Velocity of sound in dry air at 0°C, 33,136 cm/sec = 1089 ft/sec

Velocity of light in a vacuum = 2.99790×10^{10} cm/sec = 983,571,000 ft/sec = 186,284 miles/sec

Electromagnetic wave propagation velocity, c = 3×10^{8} meters/sec

Electromagnetic wave length $= \dfrac{300{,}000}{\text{f (in kilocycles)}} = \dfrac{300}{\text{f (in megacycles)}}$ in meters

Electromagnetic wave length $= \dfrac{984{,}000}{\text{f (in kilocycles}} = \dfrac{984}{\text{f (in megacycles)}}$ in feet

Astronomical unit = 9.3×10^{7} miles = 8.08×10^{7} nautical miles

Mean wave length of sodium light, 0.00005893 cm = 5893 Angstrom units

Absolute wave length of red cadmium line in air, 760 mm pressure, 15°C: 6438.4696 Angstrom units

Light year = 5.88×10^{12} miles = 5.11×10^{12} nautical miles = 6.32×10^{4}astronomical units

Parsec = 3.263 light years

Specific heat of water = 4186 joules per kg per deg

Specific heat of lead = 129 joules per kg per deg

Specific heat of copper = 383 joules per kg per deg

FIGURE 1.7 SELECTED PHYSICAL CONSTANTS (cont.)

Heat equivalent of fusion of water, 79.24 cal per gram

Heat equivalent of vaporization of water, 535.9 cal per gram

Joule equivalent = 4.186 absolute joules/calorie

Coefficient of expansion of gases, 0.003665

Specific heat of air, at constant pressure, 0.238 } 32° to 400° F
Specific heat of air, at constant volume, 0.170 }

Electromechanical equivalent of silver, 0.001118 g per sec per int. ampere

Air Gas Constant	English = 53.33	Metric = 29.27
Absolute Zero	English = -459.4° F	Metric = -273°C
Standard volume of an ideal gas at 0° C and 1 atmosphere	22.415 meter^3/(kg-mole)	
Ice Point, T_o	273.16°K	
Mechanical equivalent of heat	4.182 joule/cal	
Gravitational constant	6.670×10^{-5} dyne cm^2/gn^2	
Avogadro's number, N_o	6.0228×10^{23} (kg-mole)	
Loschmidt's number, L	7.647×10^{23} ft^{-3}	
Planck constant, h	6.624×10^{-34}joule sec	
Boltzmann constant, k	1.38047×10^{-23}joule (deg K)$^{-1}$	
Faraday's constant, F	9.652×10^{7} coulomb (kg-mole)	
Stephan - Boltzmann constant	5.672×10^{-5} erg/cm^2/deg^4/sec	
Wiens constant (displacement law)	0.2897 cm deg	
Electronic charge	1.6008×10^{-19}coulomb	
Mass of electron	2.008×10^{-30}lb = 9.108×10^{-31}kg	
Mass of proton	3.6878×10^{-27}lb = 1.6728×10^{-24}gm	
Mass of a particle	1.4625×10^{-26}lb	
Mass of hydrogen atom	3.6898×10^{-27}lb = 1.6734×10^{-24}gm	

Permeability of free space = $4\pi \times 10^{-7}$ = 1.257×10^{-6} henry per meter

Characteristic impedance of free space = 376.7 $\approx 120\pi$ ohms

Constant	Logarithm (base 10)
π = 3.1416	0.49715
$\pi/2$ = 1.5708	0.19612
$\pi/3$ = 1.0472	0.02003
$\pi/4$ = 0.7854	9.89509-10
π^2 = 9.8696	0.99430
π^3 = 31.0062	1.49145
$\sqrt{\pi}$ = 1.7725	0.24857
$3\sqrt{\pi}$ = 1.4646	0.16572

FIGURE 1.7 SELECTED PHYSICAL CONSTANTS (cont.)

Constant		Logarithm (base 10)
$3/\ \pi^2 =$	0.3183	. 9.50285-10
$1/\ \pi^3 =$	0.1013	. 9.00570-10
$1/\ \pi\ =$	0.0323	. 8.50855-10
$1/\ \pi\ =$	0.5642	. 9.75143-10

$e = 2.71828$

$1/M = \log_e 10 = 2.30258$

$\log_e 2 = 0.69314$

$1/e = 0.36787$

$\log_{10} M = \log_{10} e = 9.63778$

$\log_{10} 2 = 0.30102$

$\sqrt{2} = 1.4142$	$\sqrt{2}/2 = 0.7071$	$\sqrt{2}/3 = 0.4714$
$\sqrt{3} = 1.7321$	$\sqrt{3}/2 = 0.8660$	$\sqrt{3}/3 = 0.5773$

FIGURE 1.8 TABLE OF POWERS OF 2

2^0	1	2^{15}	32768
2^1	2	2^{16}	65536
2^2	4	2^{17}	131072
2^3	8	2^{18}	262144
2^4	16	2^{19}	524288
2^5	32	2^{20}	1048576
2^6	64	2^{21}	2097152
2^7	128	2^{22}	4194304
2^8	256	2^{23}	8388608
2^9	512	2^{24}	16777216
2^{10}	1024	2^{25}	33554432
2^{11}	2048	2^{26}	67108864
2^{12}	4096	2^{27}	134217728
2^{13}	8192	2^{28}	268435456
2^{14}	16384	2^{29}	536870912
2^{100}	1,267,650,700,229,729,301,496,703,205,776		

SECTION 2—PROPERTIES OF THE ATMOSPHERE

c = Velocity of sound in air, ft/sec

p = Absolute pressure, lb/ft ^{2}

p_o = Standard absolute pressure, lb/ft^2

T = Absolute temperature

T_o = Standard absolute temperature

V = Velocity, ft/sec

g = Acceleration of gravity, ft/sec^2

k = Exponent of compression;
ratio of specific heats

q = Impact pressure, lb/ft^2

ρ = Density, lb sec^2/ft^4

μ = Absolute viscosity, lb sec/ft^2

ν = Kinematic viscosity, ft^2/sec

σ = Density ratio, ρ/ρ_o

v = Volume, ft^3

v_o = Standard volume, ft^3

R = Universal gas constant

Z = Geopotential altitude, ft

H = Geometrical altitude, ft

F_c = Compressibility factor

FIGURE 2.1 PROPERTIES OF THE ATMOSPHERE AT SEA LEVEL

Quantity	Symbol	Metric engineering system				British engineering system			
		Unit	At probable minimum temperature	At standard temperature	At probable maximum temperature	Unit	At probable minimum temperature	At standard temperature	At probable maximum temperature
Temperature	t_0	°C	-48.0	15.0	47.0	°F	-54.5	59.0	116.6
Absolute temperature	T_0	°K	225.0	288.0	320.0	°F abs.	405.0	518.4	576.0
Pressure	p_0	mm Hg at 0°C kg/m^2 $dynes/cm^2$	760 10332.3 1.01325×10^6	760 10332 3 1.01325×10^6	760 10332.3 1.01325×10^6	in. Hg at 32°F in. water at 15°C lb/ft^2	29.9212 407.15 2116.23	29.9212 407.15 2116.23	29.9212 407.15 2116.23
Specific weight	w_0	kg/m^3 $dynes/cm^3$	1.5686 1.5383	1.2255 1.2018	1.1030 1.0816	lb/ft^3	0.097928	0.076506	0.068855
Density	$\rho_0 = \frac{w_0}{g_0}$	$kg\text{-}sec^2/m^4$	0.15995	0.124966	0.11247	$slugs/ft^3$	0.0030437	0.0023779	0.0021401
Coefficient of viscosity	μ_0	$kg\text{-}sec/m^2$ poise $(dyne\text{-}sec/cm^2)$	1.4852×10^{-6} 14565×10^{-8}	1.8187×10^{-6} 17835×10^{-8}	1.9751×10^{-6} 19369×10^{-8}	$lb\text{-}sec/ft^2$	3.0420×10^{-7}	$3\ 7250 \times 10^{-7}$	4.0455×10^{-7}
Kinematic viscosity	$\nu_0 = \frac{\mu_0}{\rho_0}$	m^2/sec	9.2848×10^{-6}	14.553×10^{-6}	17.561×10^{-6}	ft^2/sec	0.99944×10^{-4}	1.5665×10^{-4}	1.8903×10^{-4}
Speed of sound	a_0, c	m/sec km/hr	300.72 1082.6	340.22 1224.8	358.63 1291.1	ft/sec mph knots	986.61 672.69 584.16	1116.22 761.06 660.90	1176.60 802.23 696.65
Mean free path of nitrogen molecules	λ_n	m	5.76×10^{-8}	7.38×10^{-8}	8.20×10^{-8}	ft	0.1891×10^{-6}	0.2421×10^{-6}	0.2690×10^{-6}
Mean free path of oxygen molecules	λ_o	m	5.75×10^{-8}	7.36×10^{-8}	8.18×10^{-8}	ft	0.1887×10^{-6}	0.2415×10^{-6}	0.2683×10^{-6}
Mean free path of air molecules	λ_{air}	m	5.76×10^{-8}	7.37×10^{-8}	8.19×10^{-8}	ft	0.1890×10^{-6}	0.2419×10^{-6}	0.2688×10^{-6}
Average molecular weight	M_0	---	28.966	28.966	28.966	----	28.966	28.966	28.966
Ratio of specific heats	γ_0	---	1.4	1.4	1.4	----	1.4	1.4	1.4
Relative volume of oxygen	r_0	---	0.2095	0.2095	0.2095	----	0.2095	0.2095	0.2095

FIGURE 2.2 COMPOSITION OF AIR (STANDARD ATMOSPHERE)

The air of the standard atmosphere is assumed to be dry and to have the following composition at all altitudes:

Constituent Gas	Molecular Fraction, Percent	Molecular Weight (O = 16.0000)
Nitrogen, N_2	78.09	28.016
Oxygen, O_2	20.95	32.0000
Argon, A	0.93	39.944
Carbon dioxide, CO_2	0.03	44.010
Neon, Ne	1.8×10^{-3}	20.183
Helium, H	5.24×10^{-4}	4.003
Krypton, Kr	1.0×10^{-4}	83.7
Hydrogen, H_2	5.0×10^{-5}	2.0160
Xenon, Xe	8.0×10^{-6}	131.3
Ozone, O_3	1.0×10^{-6}	48.000
Radon, Rn	6.0×10^{-18}	222

FIGURE 2.3 DENSITY OF THE ATMOSPHERE AT 40° LATITUDE

Altitude		Wt	Pressure	
Ft	Mi	Lb/Cu Ft	Psi	In. Hg
SL	–	0.07651	14.70	29.92
10,000	1.9	0.05649	10.11	20.58
20,000	3.8	0.04075	6.76	13.75
30,000	5.7	0.02861	4.36	8.88
40,000	7.6	0.01872	2.72	5.54
50,000	9.5	0.01161	1.69	3.44
60,000	11.4	0.00720	1.05	2.13
70,000	13.3	0.00447	0.649	1.32
80,000	15	0.00277	0.403	0.820
90,000	17	0.00172	0.250	0.509
100,000	19	0.00107	0.155	0.315

FIGURE 2.4 ICAO STANDARD ATMOSPHERE
(USING ARDC MODEL ATMOSPHERE)

t_o	= Standard temperature at sea level	59°F
T_o	= Standard temperature absolute at sea level .	518.688°R
$t*$	= Temperature at the tropopause	-69.7°F
$T*$	= Temperature absolute at the tropopause . .	389.988°F
P_o	= Standard pressure at sea level	29.92126 in. Hg 2116.216 lb/sq ft 14.696 lb/sq in.
$P*$	= Pressure at the tropopause	6.683 in. Hg 472.68 lb/sq ft
ρ_o	= Standard density at sea level	0.076475 lb (mass)/cu ft
$\rho_o g_o$	= Standard specific weight at sea level . . .	0.076475 lb/cu ft
$\rho*$	= Density at Geopotential H*	0.022719 lb (mass)/cu ft
$H*$	= Geopotential height of the tropopause. . . .	36,089.24 ft
R	= Gas constant for dry air	53.35045 ft lb/lb°R
c_{so}	= Standard speed of sound at sea level . . .	1116.89 ft/sec
μ_o	= Coefficient of absolute viscosity at T_o . .	3.7452×10^7 lb sec/sq ft
g_s	= Standard gravitational acceleration, 45° latitude.	32.17405 ft/sec/sec
Z	= Geopotential altitude, ft.	
H	= Geometrical altitude, ft.	

ASSUMPTIONS:
The air is dry.
The air is a perfect gas.

FIGURE 2.4A ABBREVIATED TABLES OF THE ARDC MODEL ATMOSPHERE, 1956

[R. A. Minzer and W. S. Ripley AFSG No. 86, Dec. 1956, Geophysics Research Directorate, AF Cambridge Research Center, ARDC]

Z(ft)	H(ft)	T(°R)	T(°F)	P(lb/ft^2)	ρ(slugs/ft^3)	$\frac{P}{P_o}$	$\frac{\rho}{\rho_o}$
-15000	-15010.80	572.22	112.53	3546.2	3.6105^{-3}	1.67573	1.51897
	-15000	572.18	112.49	3545.0	3.6094	1.67514	1.51853
-12500	-12507.50	563.29	103.60	3264.9	3.3767	1.54281	1.42064
	-12500	563.27	103.58	3264.1	3.3761	1.54242	1.42036
-10000	-10004.80	554.37	94.679	3002.0	3.1548	1.41858	1.32728
	-10000	554.35	94.662	3001.5	3.1544	1.41835	1.32711
- 7500	- 7502.70	545.44	85.756	2756.6	2.9443	1.30261	1.23871
	- 7500	545.43	85.746	2756.4	2.9441	1.30249	1.23862
- 5000	- 5001.20	536.52	76.835	2527.7	2.7448	1.19446	1.15475
	- 5000	536.52	76.831	2527.6	2.7447	1.19441	1.15471
- 2500	- 2500.30	527.60	67.916	2314.6	2.5558	1.09372	1.07524
	- 2500	527.60	67.915	2314.5	2.5557	1.09371	1.07523
0	0	518.69	59.000	2116.2	2.3769	1.00000	1.00000
2500	2499.70	509.77	50.086	1931.9	2.2079	0.912909	0.928873
	2500	509.77	50.085	1931.9	2.2078	0.912899	0.928865
5000	4998.80	500.86	41.174	1760.9	2.0482	0.832084	0.861699
	5000	500.86	41.169	1760.8	2.0481	0.832046	0.861668
7500	7497.30	491.95	32.263	1602.3	1.8975	0.757170	0.798321
	7500	491.94	32.254	1602.2	1.8974	0.757092	0.798254
10000	9995.21	483.04	23.355	1455.6	1.7556	0.687830	0.738586
	10000	483.03	23.338	1455.3	1.7553	0.687702	0.738474
12500	12492.51	474.14	14.450	1320.0	1.6219	0.623738	0.682345
	12500	474.11	14.422	1319.6	1.6215	0.623552	0.682180
15000	14989.22	465.23	5.5461	1194.8	1.4962	0.564584	0.629453
	15000	465.20	5.5076	1194.3	1.4956	0.564339	0.629232
17500	17485.33	456.33	-3.3555	1079.4	1.3781	0.510069	0.579768
	17500	456.28	-3.4078	1078.8	1.3774	0.509762	0.579485
20000	19980.84	447.43	-12.255	973.27	1.2673	0.459909	0.533151
	20000	447.36	-12.323	972.49	1.2664	0.459540	0.532805
22500	22475.75	438.54	-21.152	875.76	1.1634	0.413831	0.489468
	22500	438.45	-21.239	874.85	1.1624	0.413402	0.489057
25000	24970.07	429.64	-30.047	786.33	1.0663	0.371574	0.448586
	25000	429.53	-30.154	785.31	1.0651^{-3}	0.371089	0.448112
27500	27463.79	420.75	-38.940	704.47	9.7544^{-4}	0.332890	0.410379
	27500	420.62	-39.069	703.33	9.7416	0.332353	0.409843
30000	29956.91	411.86	-47.831	629.66	8.9068	0.297541	0.374720
	30000	411.70	-47.985	628.43	8.8927	0.296958	0.374126
32500	32449.43	402.97	-56.720	561.44	8.1169	0.265303	0.341490
	32500	402.79	-56.900	560.12	8.1015	0.264680	0.340840
35000	34941.36	394.08	-65.607	499.34	7.3820	0.235960	0.310569
	35000	393.87	-65.816	497.95	7.3653	0.235303	0.309869
36151.73	36089.24	389.99	-69.700	472.68	7.0611^{-4}	0.223359	0.297069

FIGURE 2.4A ABBREVIATED TABLES OF THE ARDC MODEL ATMOSPHERE, 1956
[R. A. Minzer and W. S. Ripley AFSG No. 86, Dec. 1956, Geophysics Research Directorate, AF Cambridge Research Center, ARDC]

$C_s\left(\frac{ft}{sec}\right)$	C_s(knots)	$\mu\left(\frac{lb\ sec}{ft^2}\right)$	$\frac{\mu}{\mu_o}$	$\nu\left(\frac{ft^2}{sec}\right)$	$\frac{\nu}{\nu_o}$
1172.6	694.30	4.0305^{-7}	1.0783	1.1163^{-4}	0.70987
1172.6	694.28	4.0303	1.0782	1.1166	0.71004
1163.5	688.87	3.9827	1.0655	1.1794	0.75000
1163.4	688.85	3.9825	1.0655	1.1796	0.75012
1154.2	683.39	3.9345	1.0526	1.2471	0.79304
1154.2	683.38	3.9344	1.0526	1.2473	0.79312
1144.9	677.87	3.8859	1.0396	1.3198	0.83925
1144.9	677.86	3.8859	1.0396	1.3199	0.83930
1135.5	672.30	3.8370	1.0265	1.3979	0.88893
1135.5	672.30	3.8370	1.0265	1.3980	0.88896
1126.0	666.69	3.7876	1.0133	1.4820	0.94240
1126.0	666.69	3.7876	1.0133	1.4820	0.94240
1116.4	661.03	3.7379	1.0000	1.5726	1.00000
1106.8	655.33	3.6878	0.98659	1.6703	1.06214
1106.8	655.33	3.6878	0.98659	1.6703	1.06215
1097.1	649.57	3.6373	0.97307	1.7759	1.12925
1097.1	649.57	3.6373	0.97307	1.7759	1.12928
1087.3	643.77	3.5863	0.95944	1.8900	1.20183
1087.3	643.76	3.5863	0.95943	1.8901	1.20191
1077.4	637.91	3.5350	0.94570	2.0136	1.28042
1077.4	637.90	3.5349	0.94567	2.0138	1.28058
1067.4	632.01	3.4832	0.93184	2.1476	1.36564
1067.4	631.99	3.4830	0.93180	2.1480	1.36591
1057.4	626.04	3.4309	0.91786	2.2931	1.45819
1057.3	626.02	3.4307	0.91780	2.2938	1.45861
1047.2	620.02	3.3782	0.90376	2.4514	1.55883
1047.1	619.99	3.3779	0.90368	2.4524	1.55945
1036.9	613.95	3.3250	0.88954	2.6238	1.66846
1036.8	613.90	3.3246	0.88943	2.6252	1.66933
1026.6	607.81	3.2714	0.87519	2.8119	1.78804
1026.5	607.75	3.2709	0.87505	2.8138	1.78926
1016.1	601.62	3.2173	0.86071	3.0174	1.91872
1016.0	601.54	3.2166	0.86054	3.0200	1.92036
1005.5	595.36	3.1627	0.84610	3.2423	2.06176
1005.4	595.27	3.1619	0.84589	3.2457	2.06393
994.85	589.04	3.1076	0.83136	3.4890	2.21861
994.66	588.93	3.1066	0.83110	3.4934	2.22145
984.05	582.64	3.0519	0.81648	3.7600	2.39093
983.83	582.51	3.0508	0.81617	3.7657	2.39459
973.14	576.18	2.9958	0.80146	4.0582	2.58060
972.89	576.03	2.9945	0.80110	4.0656	2.58529
968.08	573.18	2.9697^{-7}	0.79449	4.2058^{-4}	2.67441

FIGURE 2.4A ABBREVIATED TABLES OF THE ARDC MODEL ATMOSPHERE, 1956 (cont.)

Z(ft)	H(ft)	T(°R)	T(°F)	P(lb/ft^2)	ρ(slugs/ft^3)	$\frac{P}{P_o}$	$\frac{\rho}{\rho_o}$
37500	37432.69	389.99	-69.700	443.12	6.6196^{-4}	2.09392^{-1}	2.78493^{-1}
	37500	389.99	-69.700	441.69	6.5982	2.08716	2.77594
40000	39923.43	389.99	-69.700	393.12	5.8727	1.85767	2.47072
	40000	389.99	-69.700	391.68	5.8511	1.85085	2.46165
42500	42413.57	389.99	-69.700	348.78	5.2103	1.64813	2.19203
	42500	389.99	-69.700	347.33	5.1887	1.64130	2.18294
45000	44903.11	389.99	-69.700	309.45	4.6227	1.46226	1.94483
	45000	389.99	-69.700	308.01	4.6012	1.45547	1.93579
47500	47392.06	389.99	-69.700	274.56	4.1015	1.29739	1.72555
	47500	389.99	-69.700	273.14	4.0803	1.29068	1.71662
50000	49880.41	389.99	-69.700	243.61	3.6391	1.15115	1.53104
	50000	389.99	-69.700	242.21	3.6183	1.14455	1.52226
52500	52368.17	389.99	-69.700	216.15	3.2290	1.02141	1.35849
	52500	389.99	-69.700	214.79	3.2086	1.01496^{-1}	1.34991
55000	54855.34	389.99	-69.700	191.80	2.8652	9.06327^{-2}	1.20542
	55000	389.99	-69.700	190.47	2.8453	9.00048	1.19707
57500	57341.91	389.99	-69.700	170.19	2.5412	8.04231	1.06911
	57500	389.99	-69.700	168.90	2.5232	7.98144	1.06154^{-1}
60000	59827.88	389.99	-69.700	151.03	2.2561	7.13658	9.49172^{-2}
	60000	389.99	-69.700	149.78	2.2375	7.07778	9.41352
70000	69765.84	389.99	-69.700	93.672	1.3993	4.42637	5.88712
	70000	389.99	-69.700	92.623	1.3837^{-4}	4.37684	5.82124
80000	79694.30	389.99	-69.700	58.125	8.6831^{-5}	2.74666	3.65308
	80000	389.99	-69.700	57.278	8.5564	2.70659	3.59980
82344.68		389.99	-69.700	51.975	7.7644^{-5}	2.45605^{-2}	3.26657^{-2}
90000		402.48	-57.204	36.291	5.2531^{-5}	1.71492^{-2}	2.21004^{-2}
	90000	403.12	-56.567	35.644	5.1513	1.68434	2.16721
100000		418.79	-40.893	23.085	3.2114	1.09087	1.35107
	100000	419.58	-40.108	22.598	3.1377	1.06784^{-2}	1.32007^{-2}
110000		435.09	-24.599	14.947	2.0014	7.06294^{-3}	8.42003^{-3}
	110000	436.04	-23.649	14.580	1.9480	6.88969	8.19559
120000		451.37	- 8.3196	9.8372	1.2697	4.64848	5.34178
	120000	452.50	- 7.1896	9.5611	1.2310^{-5}	4.51799	5.17886
130000		467.63	7.9441	6.5735	8.1894^{-6}	3.10626	3.44540
	130000	468.96	9.2696	6.3650	7.9072	3.00773	3.32668
140000		483.88	24.192	4.4552	5.3640	2.10527	2.25672
	140000	485.42	25.729	4.2972	5.1574	2.03062	2.16980
150000		500.11	40.425	3.0597	3.5642	1.44582	1.49952
151087	150000	501.88	42.188	2.9395	3.4122	1.38902	1.43555
155347	154199.475	508.79	49.100	2.5155	2.8803^{-6}	1.18866^{-3}	1.21179^{-3}
160000		508.79	49.100	2.1247	2.4329^{-6}	1.00401^{-3}	1.02355^{-3}
	160000	508.79	49.100	2.0315	2.3261	9.59953^{-4}	9.78631^{-4}
170000		508.79	49.100	1.4784	1.6929	6.98625	7.12218
	170000	508.79	49.100	1.4054	1.6093	6.64128	6.77051
175347.8		508.79	49.100	1.2180	1.3947^{-6}	5.75573^{-4}	5.86773^{-4}

FIGURE 2.4A ABBREVIATED TABLES OF THE ARDC MODEL ATMOSPHERE, 1956 (cont.)

$c_s\left(\frac{ft}{sec}\right)$	c_s(knots)	$\mu\left(\frac{lb\ sec}{ft^2}\right)$	$\frac{\mu}{\mu_o}$	$\nu\left(\frac{ft^2}{sec}\right)$	$\frac{\nu}{\nu_o}$
968.08	573.18	2.9697^{-7}	0.79449	4.4863^{-4}	2.8528
968.08	573.18	2.9697^{-7}	0.79449	4.5008	2.8620
968.08	573.18	2.9697^{-7}	0.79449	5.0568	3.2156
968.08	573.18	2.9697^{-7}	0.79449	5.0755	3.2275
968.08	573.18	2.9697^{-7}	0.79449	5.6998	3.6244
968.08	573.18	2.9697^{-7}	0.79449	5.7235	3.6395
968.08	573.18	2.9697^{-7}	0.79449	6.4243	4.0851
968.08	573.18	2.9697^{-7}	0.79449	6.4543	4.1042
968.08	573.18	2.9697^{-7}	0.79449	7.2406	4.6043
968.08	573.18	2.9697^{-7}	0.79449	7.2783	4.6282
968.08	573.18	2.9697^{-7}	0.79449	8.1605	5.1892
968.08	573.18	2.9697^{-7}	0.79449	8.2076	5.2191
968.08	573.18	2.9697^{-7}	0.79449	9.1970	5.8483
968.08	573.18	2.9697^{-7}	0.79449	9.2555^{-4}	5.8855
968.08	573.18	2.9697^{-7}	0.79449	1.0365^{-3}	6.5909
968.08	573.18	2.9697^{-7}	0.79449	1.0437	6.6369
968.08	573.18	2.9697^{-7}	0.79449	1.1686	7.4313
968.08	573.18	2.9697^{-7}	0.79449	1.1770	7.4843
968.08	573.18	2.9697^{-7}	0.79449	1.3163	8.3703
968.08	573.18	2.9697^{-7}	0.79449	1.3272	8.4398
968.08	573.18	2.9697^{-7}	0.79449	2.1223	13.495
968.08	573.18	2.9697^{-7}	0.79449	2.1463	13.648
968.08	573.18	2.9697^{-7}	0.79449	3.4201	21.748
968.08	573.18	2.9697^{-7}	0.79449	3.4708	22.070
968.08	573.18	2.9697^{-7}	0.79449	3.8248^{-3}	24.322
983.46	582.29	3.0489^{-7}	8.1566^{-1}	5.8040^{-3}	3.6907^{1}
984.24	582.75	3.0529	8.1673	5.9265	3.7686
1003.2	593.98	3.1506	8.4288	9.8107^{-3}	6.2386
1004.1	594.53	3.1555	8.4417	1.0057^{-2}	6.3949^{1}
1022.5	605.42	3.2505	8.6960	1.6241	1.0328^{2}
1023.6	606.08	3.2563	8.7114	1.6716	1.0629
1041.5	616.64	3.3486	8.9584	2.6373	1.6771
1042.8	617.41	3.3554	8.9765	2.7258	1.7333
1060.1	627.65	3.4450	9.2164	4.2067	2.6750
1061.6	628.54	3.4528	9.2372	4.3666	2.7767
1078.3	638.47	3.5398	9.4700	6.5992	4.1963
1080.0	639.48	3.5487	9.4937	6.8807^{-2}	4.3754
1096.3	649.09	3.6330	9.7193	1.0193^{-1}	6.4816
1098.2	650.23	3.6431	9.7462	1.0677	6.7892
1105.7	654.69	3.6822^{-7}	9.8510	1.2784^{-1}	8.1293^{2}
1105.7	654.69	3.6822^{-7}	9.8510^{-1}	1.5135^{-1}	9.6244^{2}
1105.7	654.69	3.6822^{-7}	9.8510^{-1}	1.5830	1.0066^{3}
1105.7	654.69	3.6822^{-7}	9.8510^{-1}	2.1751	1.3831
1105.7	654.69	3.6822^{-7}	9.8510^{-1}	2.2881	1.4550
1105.7	654.69	3.6822^{-7}	9.8510^{-1}	2.6401^{-1}	1.6788^{3}

FIGURE 2.4A ABBREVIATED TABLES OF THE ARDC MODEL ATMOSPHERE, 1956 (cont.)

Z(ft)	H(ft)	T(°R)	T(°F)	P(lb/ft^2)	ρ(slugs/ft^3)	$\frac{P}{P_o}$	$\frac{\rho}{\rho_o}$
180000		499.00	39.310	1.0274	1.1995^{-6}	4.85495^{-4}	5.04652^{-4}
	180000	495.70	36.015	9.6947^{-1}	1.1394^{-6}	4.58115	4.79357
190000		477.98	18.288	7.0468^{-1}	8.5890^{-7}	3.32989	3.61352
	190000	474.31	14.618	6.5866	8.0903	3.11246	3.40370
200000		456.95	- 2.7354	4.7518	6.0583	2.24543	2.54879
	200000	452.91	- 6.7792	4.3958	5.6545	2.07722	2.37891
210000		435.99	- 23.697	3.1493	4.2082	1.48816	1.77043
	210000	431.51	- 28.176	2.8769	3.8841	1.35944^{-4}	1.63408
220000		415.03	- 44.659	2.0452	2.8710	9.66460^{-5}	1.20785
	220000	410.11	- 49.573	1.8426	2.6175	8.70705	1.10121^{-4}
230000		394.09	- 65.602	1.2994	1.9210	6.14034	8.08180^{-5}
	230000	388.72	- 70.970	1.1523^{-1}	1.7270	5.44519	7.26582
240000		373.16	- 86.525	8.0576^{-2}	1.2580	3.80754	5.29239
	240000	367.32	- 92.367	7.0173	1.1130^{-7}	3.31596	4.68242
248999.3	246062.99	354.35	-105.34	5.1212^{-2}	8.4198^{-8}	2.41998^{-5}	3.54233^{-5}
250000		354.35	-105.34	4.8636^{-2}	7.9963^{-8}	2.29825^{-5}	3.36414^{-5}
	250000	354.35	-105.34	4.1584	6.8369	1.96502	2.87636
260000		354.35	-105.34	2.9023	4.7717	1.37146	2.00752
	260000	354.35	-105.34	2.4502	4.0283	1.15780^{-5}	1.69477
270000		354.35	-105.34	1.7328	2.8489	8.18804^{-6}	1.19855^{-5}
	270000	354.35	-105.34	1.4437	2.3735	6.82188	9.98574^{-6}
280000		354.35	-105.34	1.0350^{-2}	1.7017	4.89091	7.15922
	280000	354.35	-105.34	8.5062^{-3}	1.3985	4.01950	5.88367
290000		354.35	-105.34	6.1854	1.0170^{-8}	2.92287	4.27844
	290000	354.35	-105.34	5.0119	8.2401^{-9}	2.36832	3.46671
299517.7		354.35	-105.34	3.7914^{-3}	6.2335^{-9}	1.79161^{-6}	2.62253^{-6}
300000		354.48	-105.21	3.6984^{-3}	6.0651^{-9}	1.74765^{-6}	2.55168^{-6}
	300000	355.41	-104.28	2.9624	4.7488	1.39983^{-6}	1.99790^{-6}
325000		363.45	- 96.24	1.1105^{-3}	1.6099	5.24737^{-7}	6.77304^{-7}
	325000	366.54	- 93.15	8.8240^{-4}	1.2495^{-9}	4.16970	5.25677
350000		388.24	- 71.45	3.8144	4.9565^{-10}	1.80243	2.08525
	350000	396.75	- 62.94	3.0047	3.8102	1.41986^{-7}	1.60299^{-7}
375000		422.83	- 36.86	1.4592^{-4}	1.7183	6.89515^{-8}	7.22922^{-8}
	375000	432.29	- 27.40	1.1389^{-4}	1.3076^{-10}	5.38182	5.50113
400000		458.89	- .80	6.0962^{-5}	6.5650^{-11}	2.88073	2.76197
	400000	470.74	+ 11.05	4.7129	4.9432	2.22704	2.07967
421754.4	413385.83	491.99	32.30	3.0305^{-5}	3.0380^{-11}	1.43202^{-8}	1.27811^{-8}

FIGURE 2.4A ABBREVIATED TABLES OF THE ARDC MODEL ATMOSPHERE, 1956 (cont.)

$c_s\left(\frac{ft}{sec}\right)$	c_s(knots)	$\mu\left(\frac{lb\ sec}{ft^2}\right)$	$\frac{\mu}{\mu_o}$	$\nu\left(\frac{ft^2}{sec}\right)$	$\frac{\nu}{\nu_o}$
1095.0	648.36	3.6267^{-7}	0.97023	0.30234	1.9226^{3}
1091.4	646.22	3.6078	0.96520	0.31665	2.0135
1071.7	634.56	3.5055	0.93783	0.40814	2.5953
1067.6	632.12	3.4841	0.93210	0.43065	2.7385
1047.9	620.45	3.3819	0.90475	0.55823	3.5497
1043.3	617.69	3.3578	0.89831	0.59383	3.7761
1023.6	606.05	3.2560	0.87106	0.77373	4.9201
1018.3	602.93	3.2287	0.86377	0.83127	5.2860
998.67	591.30	3.1273	0.83663	1.0893	6.9267
992.74	587.79	3.0967	0.82845	1.1831	7.5231
973.15	576.19	2.9958	0.80146	1.5595	9.9169^{3}
966.50	572.25	2.9616	0.79232	1.7149	1.0905^{4}
946.96	560.68	2.8614	0.76551	2.2747	1.4464
939.52	556.28	2.8233	0.75532	2.5368	1.6131
922.78	546.37	2.7378^{-7}	0.73245	3.2517	2.0677^{4}
922.78	546.37	2.7378^{-7}	0.73245	3.4239	2.1772^{4}
922.78	546.37	2.7378^{-7}	0.73245	4.0045	2.5464
922.78	546.37	2.7378^{-7}	0.73245	5.7377	3.6485
922.78	546.37	2.7378^{-7}	0.73245	6.7965	4.3218
922.78	546.37	2.7378^{-7}	0.73245	9.6103	6.1111
922.78	546.37	2.7378^{-7}	0.73245	11.535	7.3349^{4}
922.78	546.37	2.7378^{-7}	0.73245	16.089	1.0231^{5}
922.78	546.37	2.7378^{-7}	0.73245	19.577	1.2449
922.78	546.37	2.7378^{-7}	0.73245	26.922	1.7120
922.78	546.37	2.7378^{-7}	0.73245	33.226	2.1128
922.78	546.37	2.7378^{-7}	0.73245	43.921	2.7929^{5}

FIGURE 2.4A ABBREVIATED TABLES OF THE ARDC MODEL ATMOSPHERE, 1956 (cont.)

Z(ft)	H(ft)	T(°R)	T(°F)	P(lb/ft²)	ρ(slugs/ft³)	$\frac{P}{P_0}$	$\frac{\rho}{\rho_0}$
425000		506.34	46.65	2.74378^{-5}	2.6717^{-11}	1.29655^{-8}	1.12402^{-8}
	425000	545.24	85.55	2.12392	1.9188	1.00364^{-8}	8.07259^{-9}
450000		615.41	155.72	1.39121	1.1105^{-11}	6.57404^{-9}	4.67182
	450000	658.11	198.42	1.09901^{-5}	8.1873^{-12}	5.19328	3.44450
475000		722.53	262.84	7.90580^{-6}	5.3484	3.73581	2.25014
	475000	769.60	309.91	6.32743	4.0104	2.99997	1.68721
500000		828.36	368.67	4.87456	2.8624	2.30343	1.20425^{-9}
	500000	879.84	420.15	4.28470	2.3630	2.02469	9.94166^{-10}
550000		1036.99	577.30	2.19478	1.0204^{-12}	1.03712^{-9}	4.29278
	550000	1098.68	638.99	1.78780	7.8272^{-13}	8.44805^{-10}	3.29301
590400.3	574146.9	1204.32	744.63	1.2927^{-6}	5.1471^{-13}	6.10850^{-10}	2.16547^{-10}
600000		1218.86	759.17	1.1521^{-6}	4.4987	5.44428^{-10}	1.89266^{-10}
	600000	1244.83	785.14	9.3660^{-7}	3.5308	4.42583	1.48544^{-10}
650000		1289.47	829.78	6.5534	2.3251	3.09673	9.78216^{-11}
	650000	1316.91	857.22	5.2586	1.7973	2.48492	7.56165
700000		1353.70	894.01	3.9251	1.2766^{-13}	1.85478	5.37071
	700000	1383.20	923.51	3.1087	9.7181^{-14}	1.46899	4.08851
750000		1413.56	953.87	2.4546	7.3717	1.15990^{-10}	3.10136
	750000	1445.79	986.10	1.9187	5.5261	9.06646^{-11}	2.32491
800000		1470.75	1011.1	1.5922	4.4430	7.52397	1.86924
	800000	1506.71	1047.0	1.2283	3.2797	5.80410	1.37981
850000		1526.69	1067.0	1.0658^{-7}	2.7782	5.03644	1.16882^{-11}
	850000	1567.28	1107.6	8.1140^{-8}	2.0193	3.83417	8.49546^{-12}
900000		1582.72	1123.0	7.3318	1.7935	3.46459	7.54562
	900000	1628.23	1168.5	5.5083	1.2836	2.60288	5.40022
950000		1638.85	1179.2	5.1657	1.1907^{-14}	2.44099	5.00944
	950000	1690.37	1230.7	3.8298	8.3906^{-15}	1.80975	3.53005
1000000		1695.73	1236.0	3.7172	8.1027	1.75653	3.40893
	1000000	1754.23	1294.5	2.7197	5.6221	1.28516^{-11}	2.36528
1100000		1812.49	1352.8	2.0325	3.9989	9.60452^{-12}	1.68240
	1100000	1885.93	1426.2	1.4483	2.6901	6.84358	1.13174^{-12}
1200000		1933.06	1473.4	1.1812^{-8}	2.1193	5.58143	8.91619^{-13}
	1200000	2023.61	1563.9	8.1967^{-9}	1.3823	3.87328	5.81536
1300000		2056.96	1597.3	7.2168	1.1910^{-15}	3.41024	5.01067
	1300000	2166.36	1706.7	4.8779	7.5321^{-16}	2.30500	3.16886
1400000		2183.55	1723.9	4.5985	7.0299	2.17297	2.95759
1500000		2312.72	1853.0	3.0365	4.3262	1.43487	1.82010
	1400000	2313.64	1854.0	3.0275	4.3113	1.43063^{-12}	1.81381
1600000		2443.22	1983.5	2.0675	2.7596	9.76987^{-13}	1.16101
	1500000	2464.50	2004.8	1.9474	2.5731	9.20248	1.08253^{-13}
1700000		2574.38	2114.7	1.4458	1.8161	6.83190	7.64038^{-14}
	1600000	2617.73	2158.0	1.2918	1.5919	6.10439	6.69753
1780465.88	1640419.9	2680.40	2220.7	1.1029^{-9}	1.3231	5.21161	5.56655
	1700000	2773.04	2313.4	8.8015^{-10}	1.0162^{-16}	4.15907^{-13}	4.27541^{-14}

FIGURE 2.5 REAL KINETIC TEMPERATURE vs. GEOMETRIC ALTITUDE (ICAO)

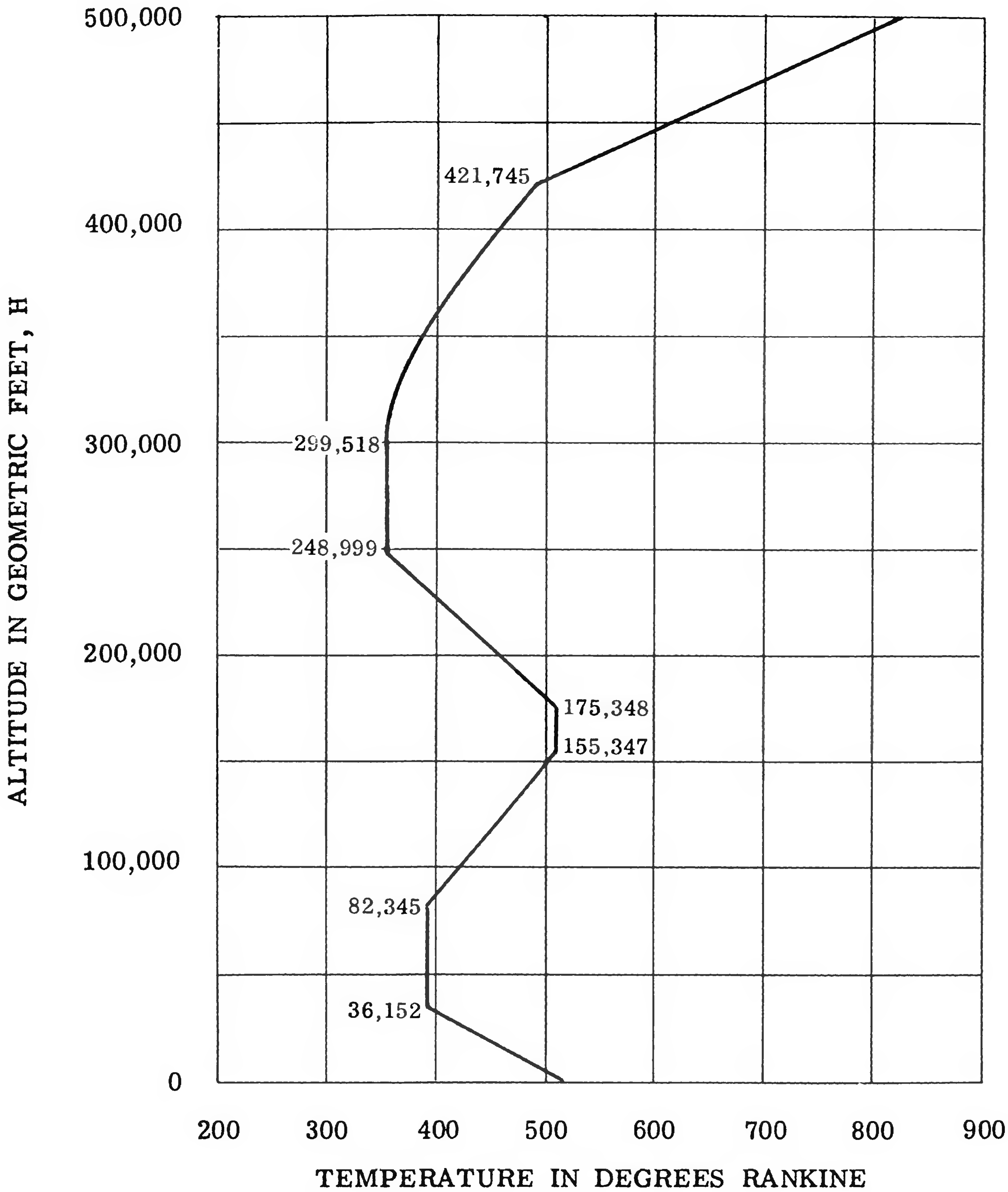


FIGURE 2.6 PRESSURE vs. GEOMETRIC ALTITUDE (ICAO)

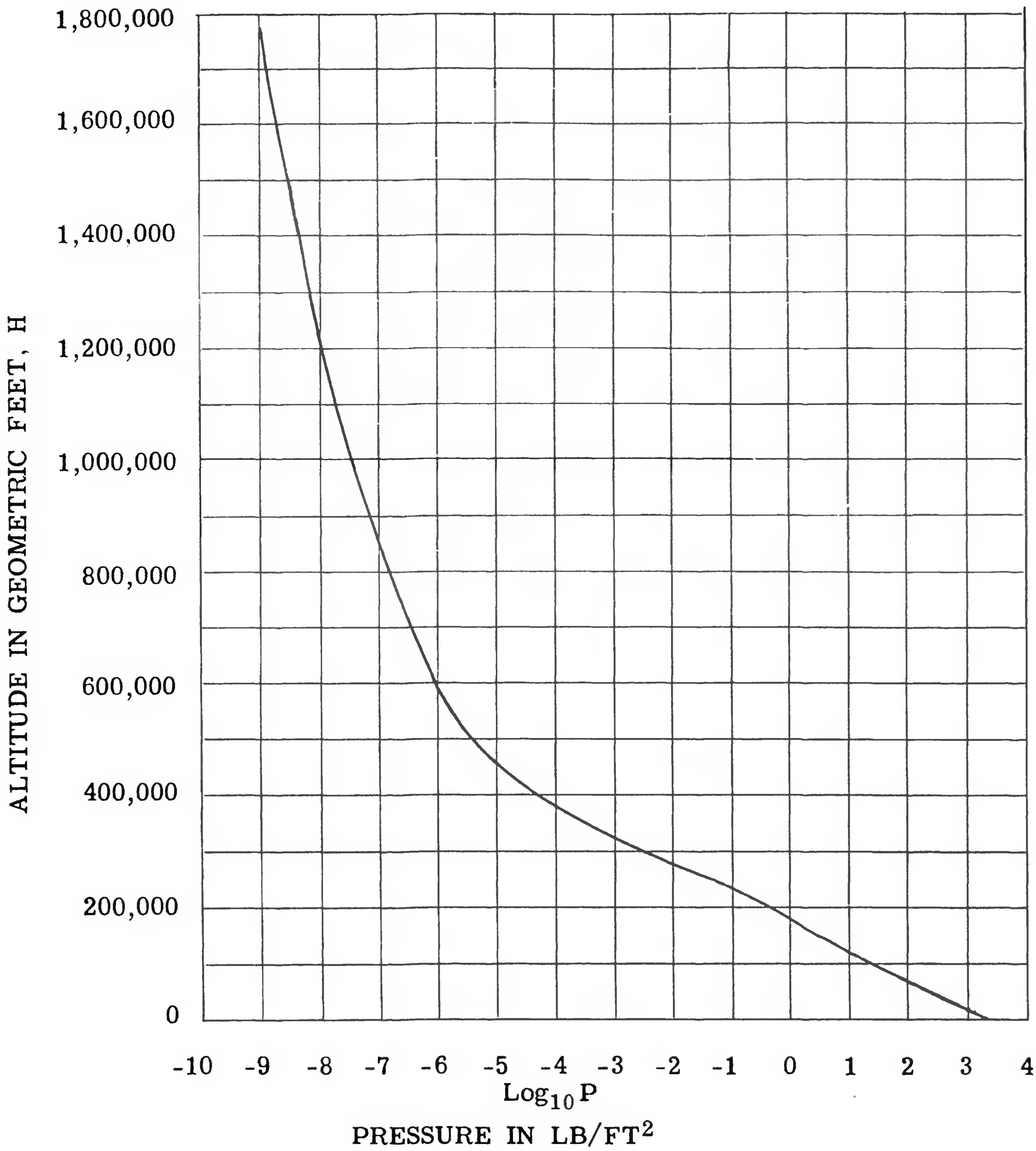


FIGURE 2.7 SOUND SPEED vs. GEOMETRIC ALTITUDE (ICAO)

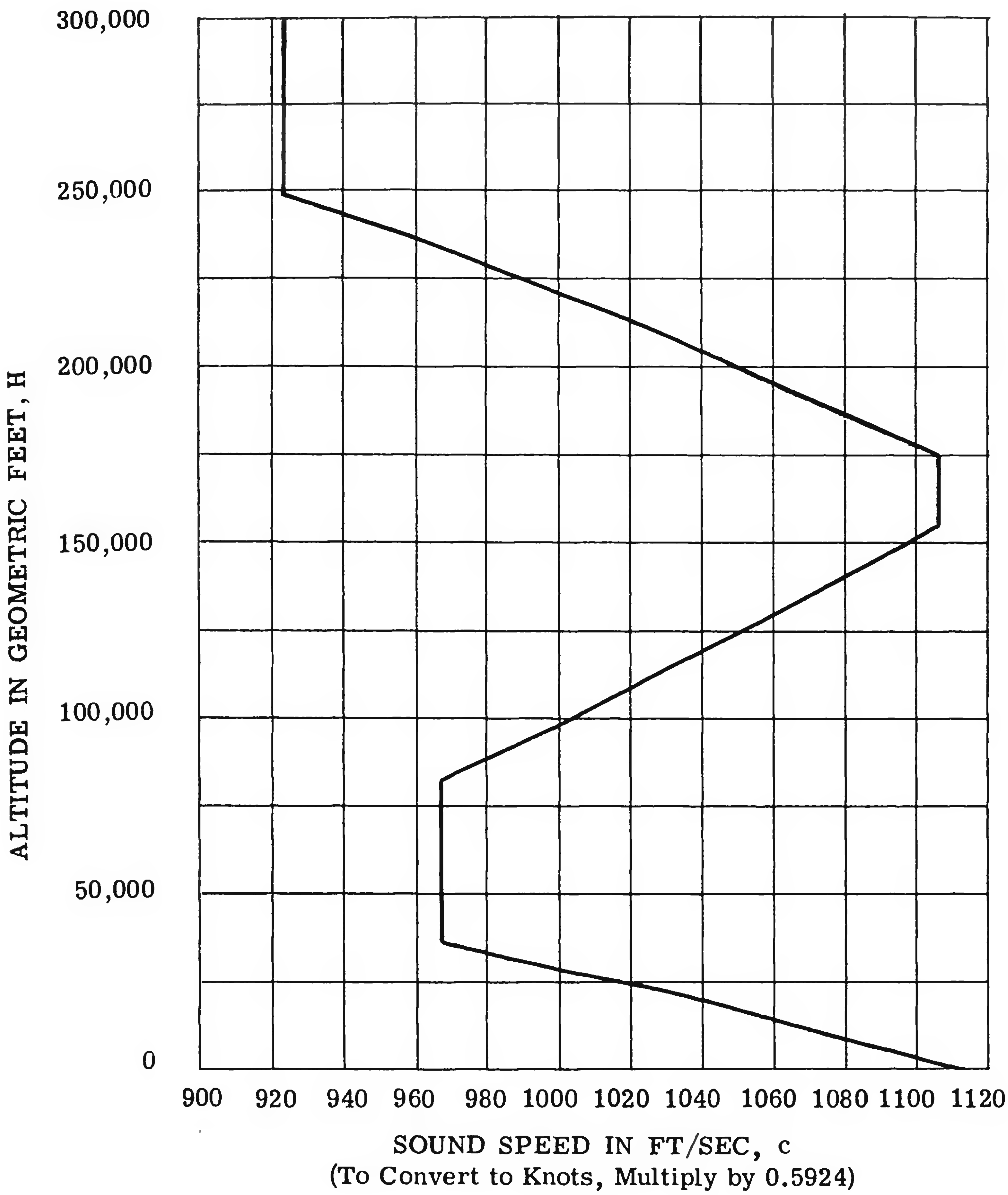


FIGURE 2.8 SPEED OF SOUND IN AIR AT VARIOUS ALTITUDES

$a\ (\text{mph}) = 33.42\sqrt{T}$ $a\ (\text{knots}) = 29.04\sqrt{T}$

where T is absolute air temperature (F) at altitude from NACA Standard Atmosphere Table

Altitude Ft x 1000	a			Altitude Ft x 1000	a		
	Mph	Knots	Ft/Sec		Mph	Knots	Ft/Sec
0	760.9	661.2	1116	20	706.6	614.0	1036
1	758.3	658.9	1112	21	703.8	611.6	1032
2	755.7	656.7	1108	22	701.0	609.2	1028
3	753.0	654.3	1104	23	698.1	606.6	1024
4	750.4	652.1	1101	24	695.3	604.2	1020
5	747.7	649.7	1097	25	692.4	601.7	1016
6	745.1	647.5	1093	26	689.5	599.2	1011
7	742.3	645.0	1089	27	686.6	596.6	1007
8	739.7	642.8	1085	28	683.7	594.1	1003
9	737.0	640.4	1081	29	680.8	591.6	999
10	734.3	638.1	1077	30	677.9	589.1	994
11	731.6	635.7	1073	31	674.9	586.5	990
12	728.8	633.3	1069	32	672.0	584.0	986
13	726.1	631.0	1065	33	669.0	581.3	981
14	723.4	628.6	1061	34	666.0	578.7	977
15	720.6	626.2	1057	35	663.0	576.1	972
16	717.8	623.8	1053	36	662.0	575.3	971
17	715.0	621.3	1049	40	662.0	575.3	971
18	712.2	618.9	1045	45	662.0	575.3	971
19	709.4	616.5	1040	50	662.0	575.3	971

FIGURE 2.9 VELOCITY OF SOUND VS. ALTITUDE (TO 390,000 FT)
[from HANDBOOK OF SUPERSONIC AERODYNAMICS, 1950]

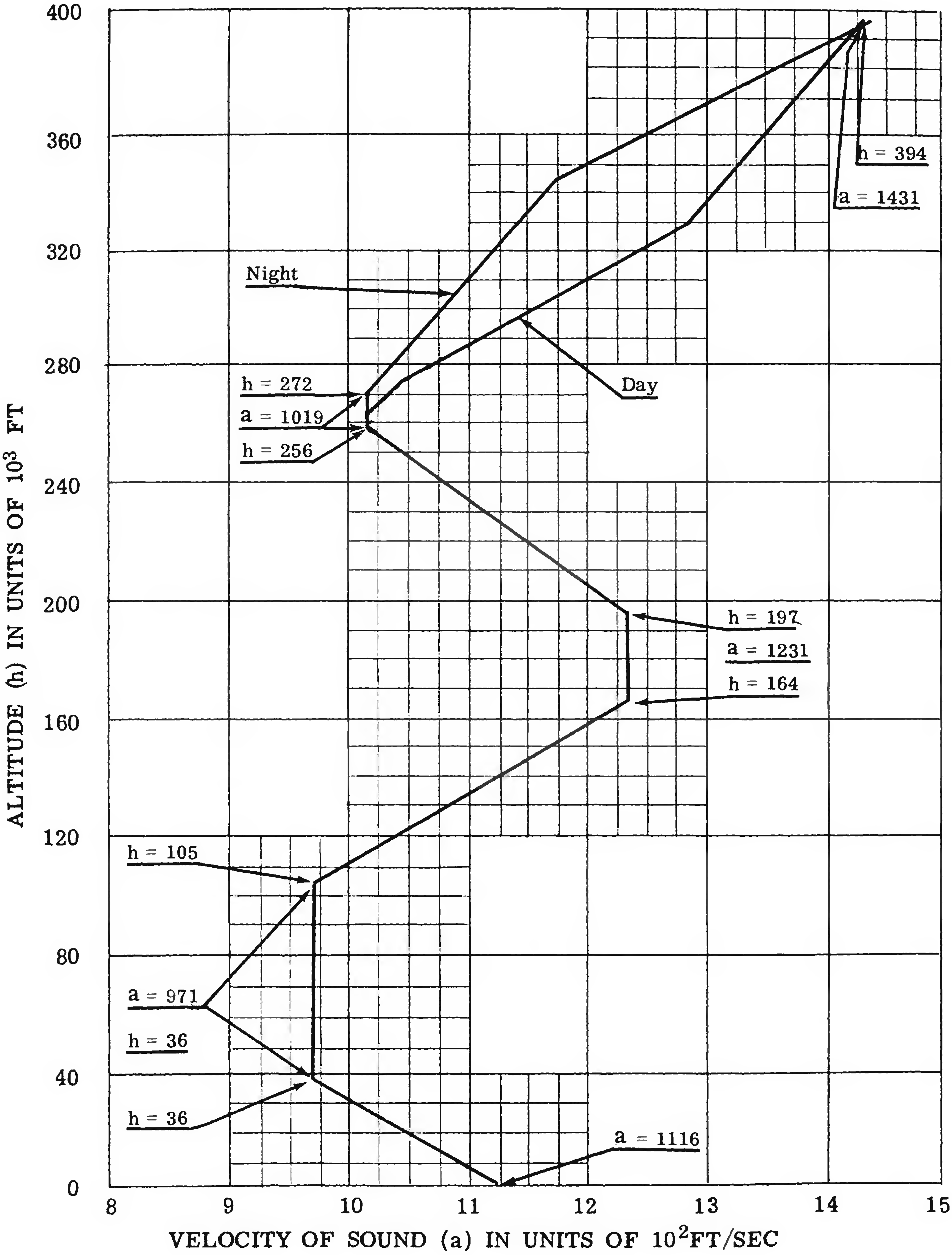


FIGURE 2.10 SPEED OF SOUND VS. TEMPERATURE

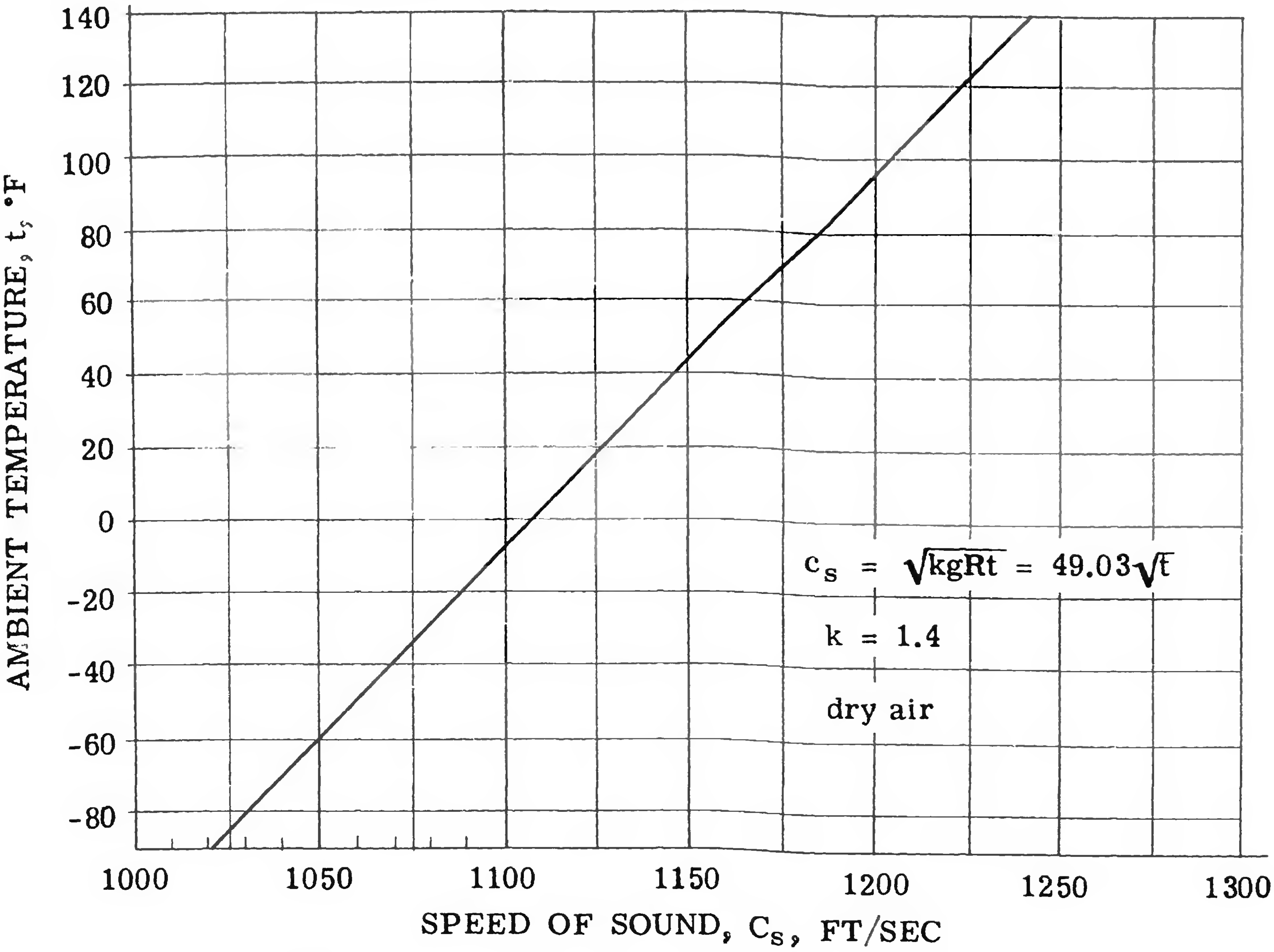


FIGURE 2.11 MISCELLANEOUS PROPERTIES OF AIR

Temperature °F	Temperature °C	c* Specific Heat, $\frac{Btu}{(lb)(°F)}$	ρ** Density, $\frac{lb}{cu\ ft}$	μ, Viscosity, $\frac{lb}{(ft)(hr)}$	k, Thermal Conductivity, $\frac{Btu}{(hr)(ft)(°F)}$	$\frac{c\mu}{k}$ Prandtl Number	β Coeff. of Thermal Expansion $\frac{1}{°R}$	a x 10^{-6}** Free convection Modulus, $\frac{1}{(cu\ ft)(°F)}$
-50	-46	0.239	0.0968	0.036	0.0116	0.74	0.00244	5.46
0	-17.8	0.239	0.0863	0.040	0.0132	0.72	0.00217	3.00
50	10.0	0.240	0.0779	0.043	0.0145	0.71	0.00196	1.81
100	37.8	0.240	0.0708	0.046	0.0158	0.70	0.00179	1.20
150	65.6	0.241	0.0651	0.049	0.0170	0.70	0.00164	0.82
200	93.3	0.241	0.0601	0.052	0.0182	0.69	0.00152	0.58
250	121.1	0.242	0.0550	0.055	0.0192	0.68	0.00141	0.41
300	148.9	0.242	0.0522	0.058	0.0240	0.68	0.00132	0.31
350	176.7	0.243	0.0490	0.060	0.0216	0.68	0.00123	0.23
400	204.4	0.245	0.0461	0.062	0.0227	0.67	0.00116	0.18
450	232.2	0.246	0.0436	0.065	0.0239	0.67	0.00110	0.14
500	260.0	0.247	0.0413	0.067	0.0250	0.66	0.00104	0.11
550	288.0	0.249	0.0393	0.070	0.0264	0.66	0.00099	0.086
600	315.0	0.250	0.0374	0.072	0.0271	0.66	0.00094	0.069
650	343.0	0.252	0.0358	0.074	0.0282	0.66	0.00090	0.055
700	371.1	0.253	0.0342	0.076	0.0291	0.66	0.00086	0.044

* Specific Heat at Constant Pressure

** Density and Convection Modulus for Atmospheric Pressure (29.92 in. Hg)

FIGURE 2.12 AIR FLOW EQUATIONS

1. General form of Bernoulli's equation

$$\frac{dp}{\rho} + VDV = 0$$

2. Incompressible flow

$$p + \frac{1}{2}\rho V^2 = H = \text{constant}$$

3. Compressible flow

$$\frac{p_2}{p_1} = 1 - \frac{k-1}{2}\left(\frac{V_2^2 - V_1^2}{a_1^2}\right)^{\frac{k}{k-1}}$$

True airspeed, ft/sec

$$q = 1/2\rho V^2 = \text{lb/ft}^2 \text{ for } V \text{ in ft/sec}$$

True airspeed, MPH

$$q(\text{lb/ft}^2) = 1.076\ \rho\ V_T^2 = \frac{\sigma V_T^2}{391}$$

True airspeed, knots

$$q(\text{lb/ft}^2) = 1.426\ \rho\ V_T^2 = \frac{\sigma V_T^2}{295}$$

Compressibility factor

$$q_c = qF_c$$

$$F_c = 1 + \frac{M^2}{4} + \frac{M^4}{40} + \frac{M^6}{1600} + \ldots$$

4. Temperature rise due to adiabatic compression

$$\Delta t(°F) = 1.794 \frac{V_T^2}{100}$$ V_T = true airspeed in MPH

$$\Delta t(°C) = .997 \frac{V_T^2}{100}$$ V_T = true airspeed in MPH

$$\Delta t(°F) = 2.379 \frac{V_T^2}{100}$$ V_T = true airspeed in KNOTS

$$\Delta t(°C) = 1.322 \frac{V_T^2}{100}$$ V_T = true airspeed in KNOTS

FIGURE: 2.13 MACH NUMBER VS. AIRSPEED (VARIOUS ALTITUDES)

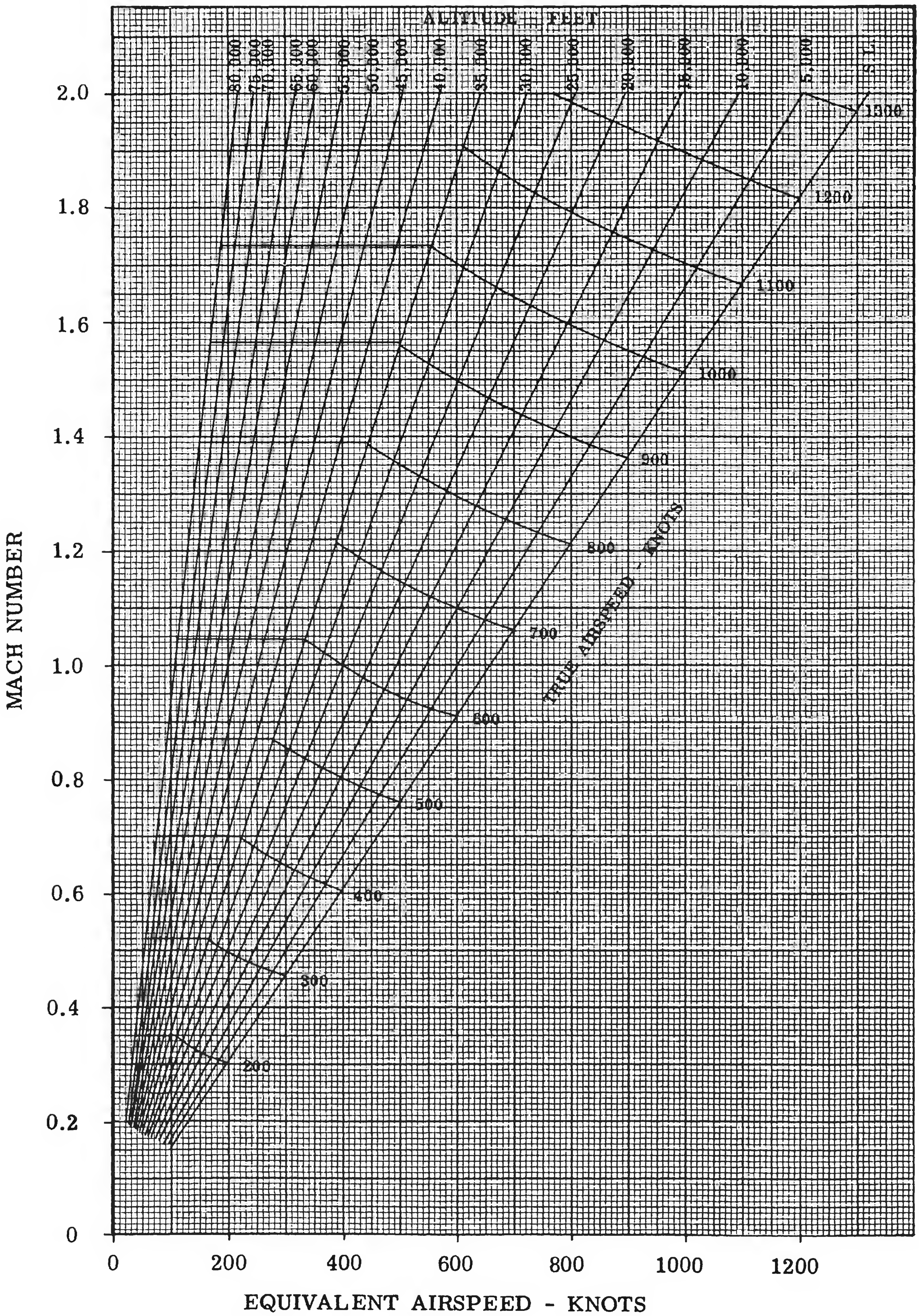


FIGURE 2.14(A) DYNAMIC PRESSURE (q) AS A FUNCTION OF MACH NUMBER (M), WITH ALTITUDE (H) AS A PARAMETER, FOR THE NACA STANDARD ATMOSPHERE
[from HANDBOOK OF SUPERSONIC AERODYNAMICS, 1950]

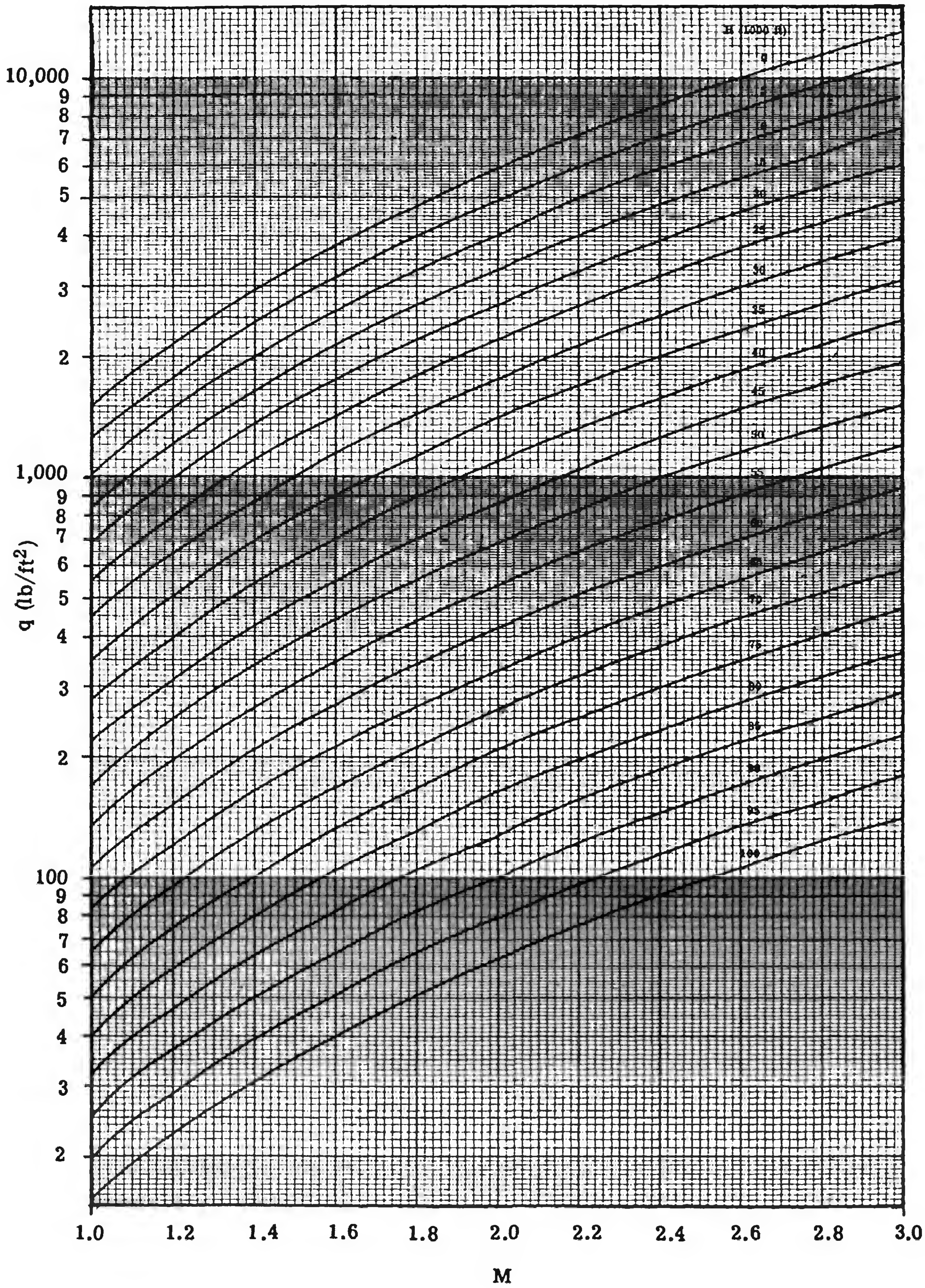


FIGURE 2.14(B) DYNAMIC PRESSURE (q) AS A FUNCTION OF MACH NUMBER (M), WITH ALTITUDE (H) AS A PARAMETER, FOR THE NACA STANDARD ATMOSPHERE
[from HANDBOOK OF SUPERSONIC AERODYNAMICS, 1950]

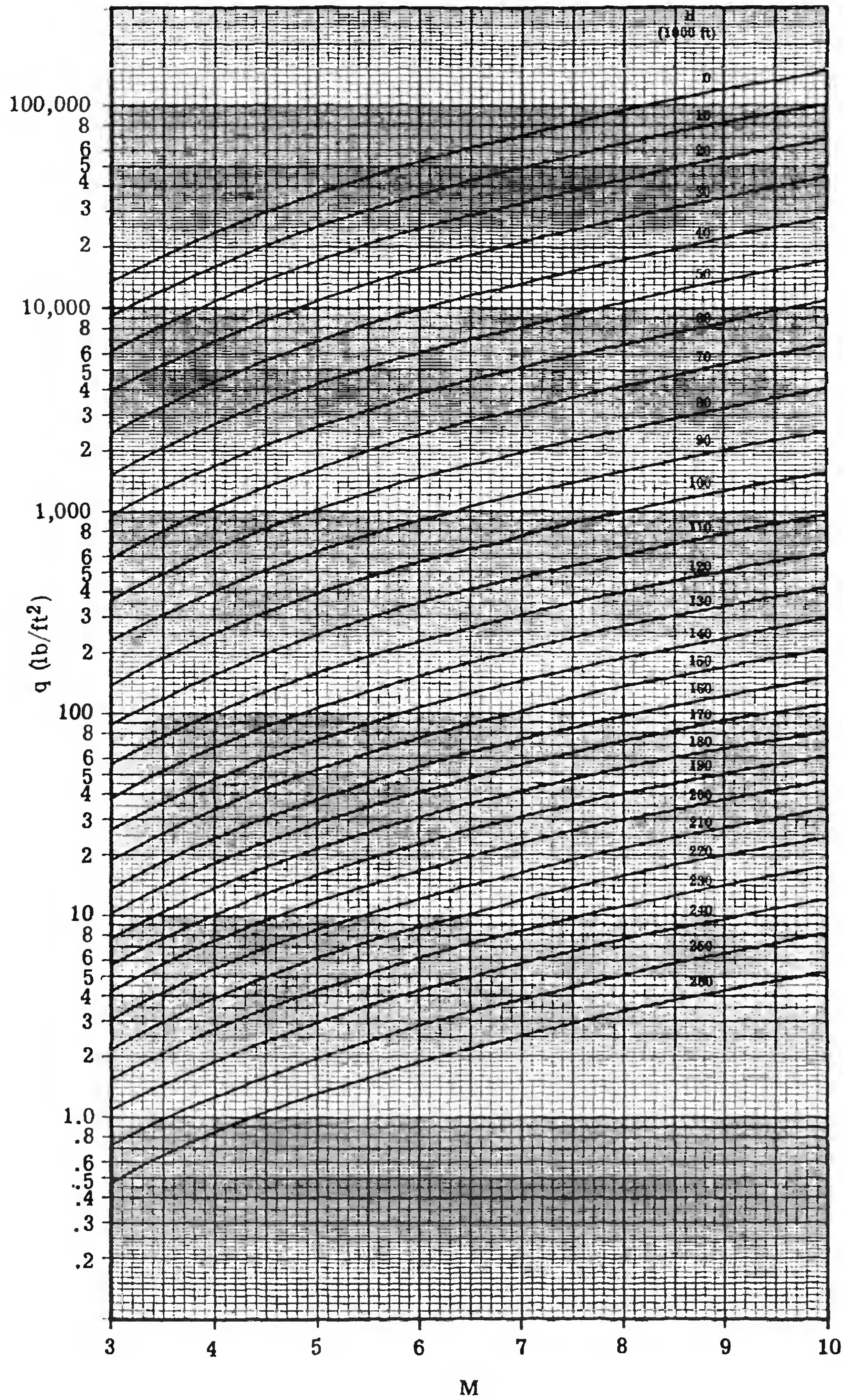


FIGURE 2.15 IMPACT PRESSURE VS AIRSPEED

Sea Level - NACA Standard Atmosphere

Note: Supersonic pressures are free stream pressures ahead of shock wave

Airspeed			Impact Pressure (Pitot minus Static) Compressible Adiabatic		
Mph	Knots	Ft/Sec	In. H_2O	Lb/Ft^2	$Lb/In.^2$
20	17.4	29.3	0.197	1.023	0.007
40	34.8	58.7	0.788	4.095	0.028
60	52.1	88.0	1.774	9.222	0.064
80	69.5	117.3	3.158	16.41	0.114
100	86.9	146.7	4.943	25.69	0.178
120	104.3	176.0	7.131	37.06	0.257
140	121.7	205.3	9.729	50.56	0.351
160	139.0	234.7	12.740	66.21	0.460
180	156.4	264.0	16.171	84.04	0.584
200	173.8	293.3	20.031	104.1	0.723
220	191.2	322.7	24.322	126.4	0.878
240	208.6	352.0	29.055	151.0	1.049
260	225.9	381.3	34.251	178.0	1.236
280	243.3	410.7	39.908	207.4	1.440
300	260.7	440.0	46.046	239.3	1.662
320	278.1	469.3	52.665	273.7	1.901
340	295.5	498.7	59.785	310.7	2.158
360	312.8	528.0	67.424	350.4	2.433
380	330.2	557.3	75.602	392.9	2.728
400	347.6	586.7	84.338	438.3	3.044
450	391.0	660.0	108.679	564.8	3.922
500	434.5	733.3	136.888	711.4	4.940
600	521.4	880.0	206.47	1073	7.45
700	608.3	1026.7	296.52	1541	10.70
760.9	661.2	1116.1	363.48	1889	13.12
1000	869.0	1466.7	742.74	3860	26.81
1200	1042.8	1760.0	1265.74	6578	45.68
1400	1216.6	2053.3	2080.06	10,810	75.07
1600	1390.4	2346.7	3331.75	17,315	120.24
1800	1564.2	2640.0	5239.98	27,232	189.11
2000	1738.0	2933.3	8075.29	41,967	291.44

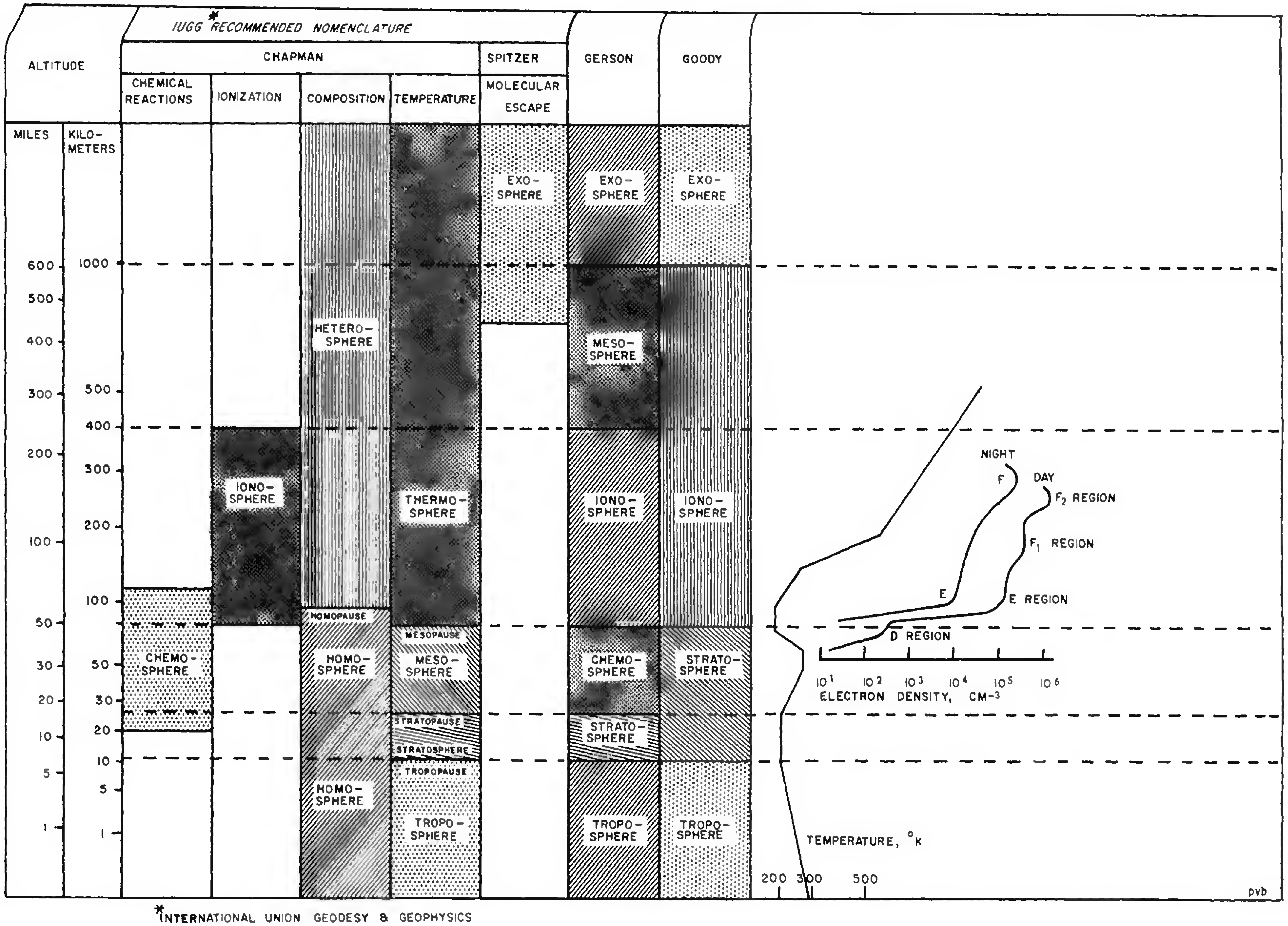
True impact pressure, q_c, and pressure altitude, H_p are related to Mach number by the following relation:

$$M = \left\{ \frac{2}{k-1} \left[\left(1 + \frac{q_c}{p}\right)^{\frac{k-1}{k}} - 1 \right] \right\}^{1/2}$$

where p = pressure corresponding to pressure altitude, H_p.

[Figure 2.16]

FIGURE 2.16 COMPARISON OF ATMOSPHERE NOMENCLATURE



*INTERNATIONAL UNION GEODESY & GEOPHYSICS

Reference: Chart prepared by G. W. Wares for Atmospheric Shells, Chapter I, in "Handbook of Geophysics for Air Force Designers" Geophysics Research Directorate, AFCRC, in press Nov. 1957.

SECTION 3—ENVIRONMENTAL DATA AND RELIABILITY

FIGURE 3.1 CHARACTERISTICS OF STANDARD DAYS

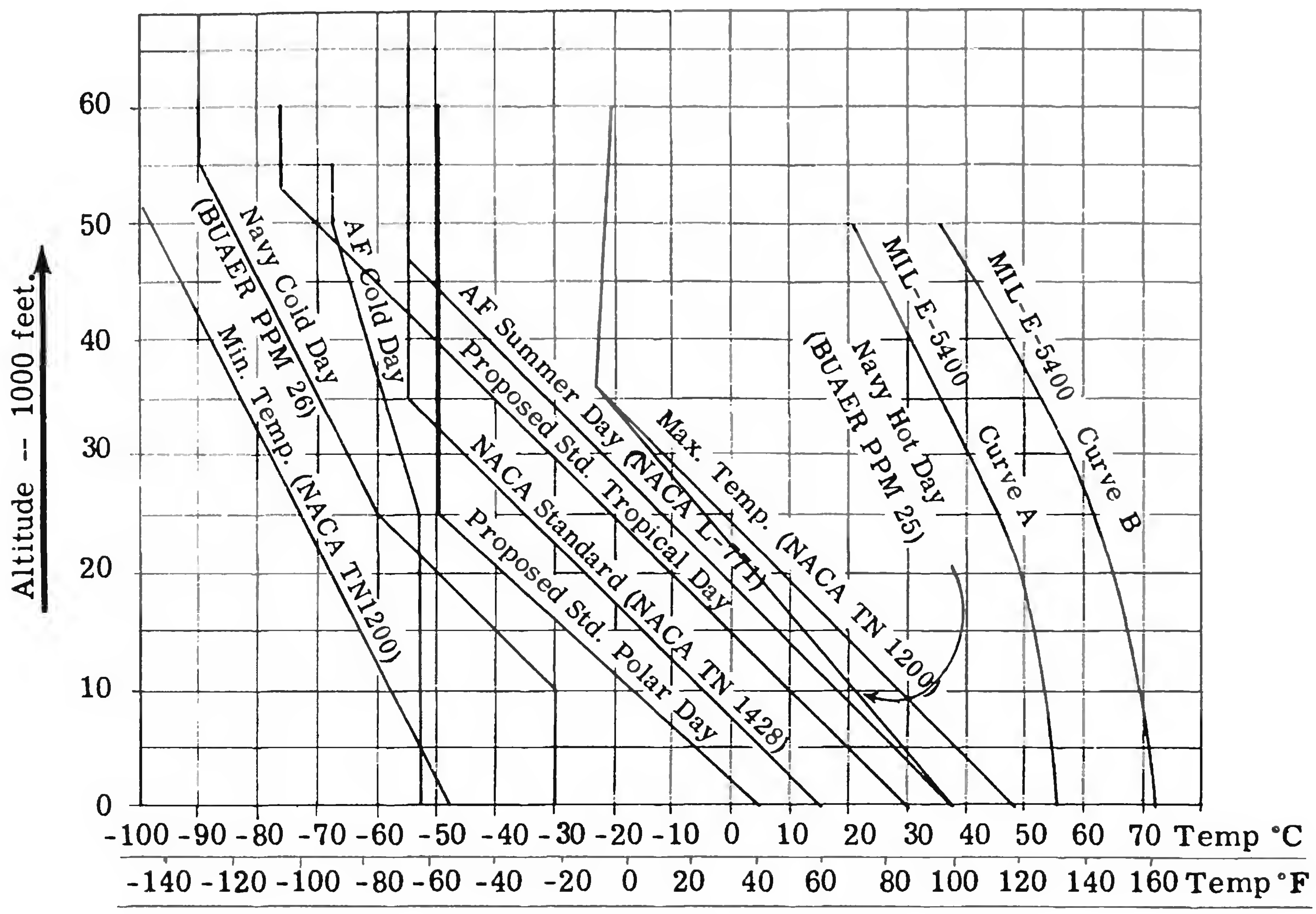


FIGURE 3.2 DENSITY AND PRESSURE VARIATION WITH ALTITUDE, STANDARD DAY

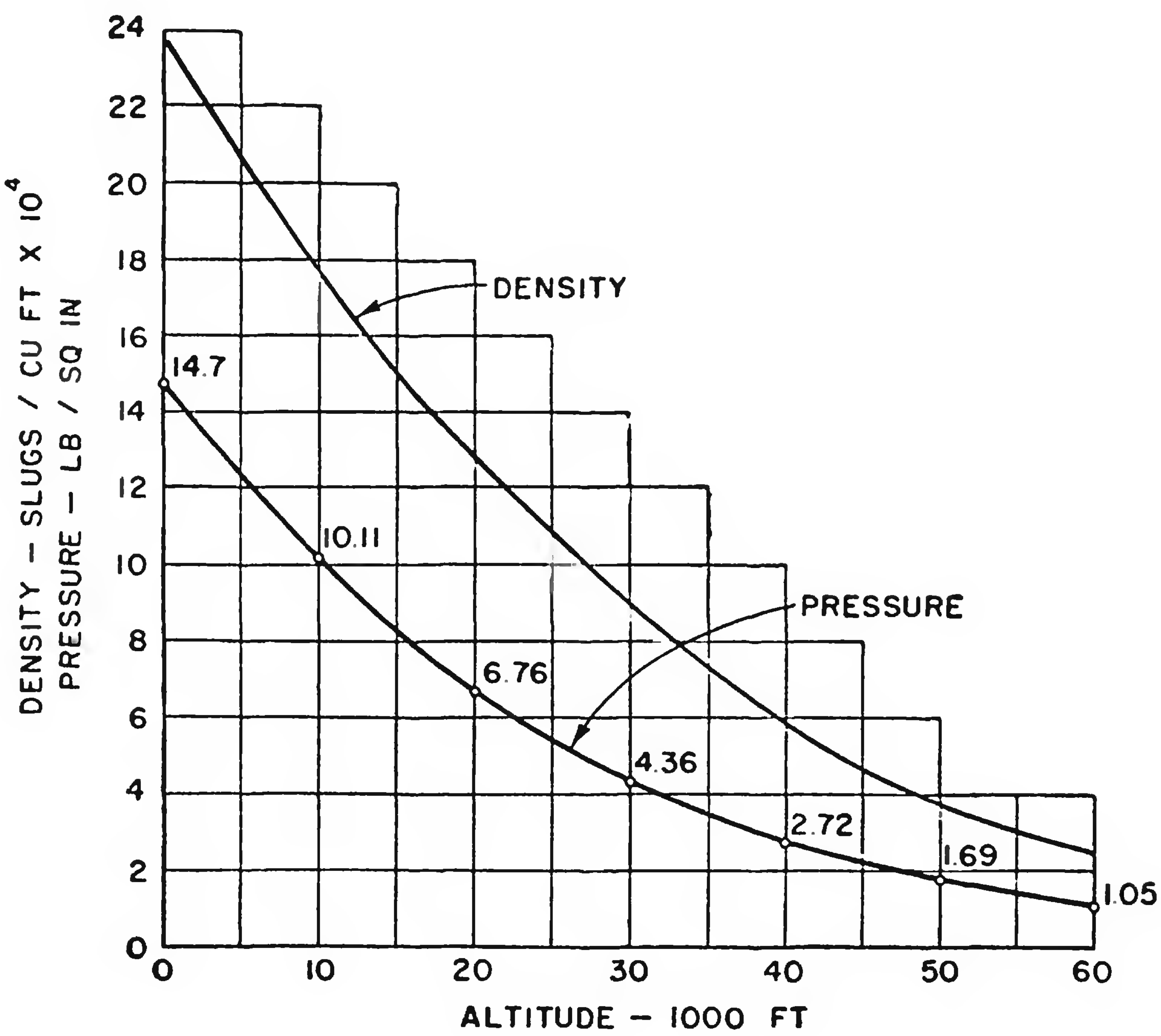


FIGURE 3.3 MACH NUMBER VS. ALTITUDE FOR VARIOUS SPEEDS AND TYPES OF DAY

Velocity (ft/sec)	Day	Altitude (ft)						
		Sea Level	10,000	20,000	30,000	40,000	50,000	60,000
1500	Standard	1.34	1.39	1.45	1.51	1.54	1.54	1.54
	Hot	1.29	1.34	1.38	1.44	1.49	1.49	1.49
	Cold	1.46	1.46	1.53	1.58	1.62	1.66	1.68
	Polar	1.37	1.42	1.48	1.50	1.50	1.50	1.50
	Tropical	1.30	1.35	1.40	1.45	1.52	1.59	1.62
2000	Standard	1.79	1.86	1.93	2.01	2.06	2.06	2.06
	Hot	1.72	1.78	1.85	1.92	1.99	1.99	1.99
	Cold	1.95	1.95	2.03	2.11	2.16	2.21	2.25
	Polar	1.82	1.87	1.97	2.01	2.01	2.01	2.01
	Tropical	1.74	1.80	1.86	1.94	2.03	2.12	2.16
2500	Standard	2.24	2.32	2.41	2.51	2.57	2.57	2.57
	Hot	2.15	2.23	2.31	2.40	2.49	2.49	2.49
	Cold	2.44	2.44	2.54	2.63	2.70	2.77	2.80
	Polar	2.28	2.34	2.46	2.51	2.51	2.51	2.51
	Tropical	2.17	2.25	2.33	2.42	2.53	2.65	2.70
3000	Standard	2.69	2.78	2.89	3.01	3.09	3.09	3.09
	Hot	2.58	2.67	2.77	2.88	2.98	2.98	2.98
	Cold	2.92	2.92	3.05	3.16	3.24	3.32	3.37
	Polar	2.73	2.84	2.96	3.01	3.01	3.01	3.01
	Tropical	2.61	2.70	2.80	2.91	3.04	3.18	3.24
4000	Standard	3.58	3.71	3.86	4.02	4.12	4.12	4.12
	Hot	3.45	3.56	3.69	3.84	3.98	3.98	3.98
	Cold	3.90	3.90	4.07	4.21	4.32	4.43	4.49
	Polar	3.64	3.75	3.94	4.01	4.01	4.01	4.01
	Tropical	3.48	3.59	3.73	3.88	4.05	4.23	4.32

FIGURE 3.4 SPEED VS. ALTITUDE FOR VARIOUS MACH NUMBERS AND TYPES OF DAY

Mach No.	Day	Altitude (ft)						
		Sea Level	10,000	20,000	30,000	40,000	50,000	60,000
1.5	Standard	1676	1617	1556	1492	1458	1458	1458
	Hot	1742	1685	1625	1564	1508	1508	1508
	Cold	1539	1539	1475	1425	1389	1355	1336
	Polar	1647	1587	1522	1491	1491	1491	1491
	Tropical	1726	1668	1608	1546	1481	1413	1390
2.0	Standard	2234	2156	2074	1990	1944	1944	1944
	Hot	2322	2246	2166	2086	2010	2010	2010
	Cold	2052	2052	1966	1900	1852	1806	1782
	Polar	2196	2116	2030	1988	1988	1988	1988
	Tropical	2302	2224	2144	2062	1978	1890	1854
2.5	Standard	2792	2695	2592	2488	2430	2430	2430
	Hot	2902	2808	2708	2608	2512	2512	2512
	Cold	2565	2565	2458	2375	2315	2258	2228
	Polar	2745	2644	2538	2485	2485	2485	2485
	Tropical	2878	2780	2680	2578	2473	2362	2318
3.0	Standard	3351	3234	3111	2985	2916	2916	2916
	Hot	3483	3369	3249	3129	3015	3015	3015
	Cold	3078	3078	2949	2850	2778	2709	2673
	Polar	3294	3173	3045	2982	2982	2982	2982
	Tropical	3452	3335	3216	3093	2966	2834	2781
4.0	Standard	4468	4312	4148	3980	3888	3888	3888
	Hot	4644	4492	4332	4172	4020	4020	4020
	Cold	4104	4104	3932	3800	3704	3612	3564
	Polar	4392	4231	4060	3976	3976	3976	3976
	Tropical	4604	4447	4288	4124	3957	3779	3708

FIGURE 3.5 CLIMATIC EXTREMES FOR MILITARY EQUIPMENT

EXTREME STRESS CONDITIONS		ENVIRONMENTAL FACTORS	OPERATION: GROUND (OUTDOORS) WORLD - WIDE	OPERATION: GROUND (OUTDOORS) ARCTIC WINTER	OPERATION: GROUND (OUTDOORS) MOIST TROPICS	OPERATION: GROUND (OUTDOORS) HOT DESERT	OPERATION: SHIPBOARD (WORLD-WIDE)	SHORT-TERM STORAGE & TRANSIT LAND-SEA-AIR (WORLD-WIDE)
THERMAL	HOT	DURATION (hours) AIR TEMPERATURE (°F) RADIATION (watts/ft²) UV<4000Å IR>7000Å WIND SPEED (mph)	10, 90, 0, 0, 0, 7 ; 5, 6, 50, 7 ; 4, 125, 105, 6, 50, 7 ; 5, 6, 50, 7		10, 75, 0, 0, 0, 4 ; 5, 45, 51, 4 ; 4, 95, 90, 45, 51, 4 ; 5, 45, 51, 4	W	10, 90, 0, 0, 0, 6 ; 5, 4.5, 51, 6 ; 4, 100, 90, 45, 51, 6 ; 5, 45, 51, 6 Sea Surface 95°F	10, 90, 0, 0, 0, 0 ; 5, 0, 0, 0, 0 ; 4, 160, 0, 0, 0, 0 ; 5, 0, 0, 0, 0
THERMAL	COLD	DURATION (hours) AIR TEMPERATURE (°F) SKY TEMPERATURE (°F) WIND SPEED	EQUILIBRIUM, -40 ; 72, -65, -80, 5mph	W			24, -20, -45, 40 knots	EQUILIBRIUM, -40, 0 ; 24, -80, 0
HUMIDITY	HIGH	ABS HUMID (grains/ft³)	13	21	W	W	W	W
HUMIDITY	HIGH	DURATION (hours) RELATIVE HUMIDITY (%) AIR TEMPERATURE (°F)	20, 93 to 97, 80 to 85 ; 4, 100 w/cond, 75 to 80	98 to 100 below freezing	W		W	W
HUMIDITY	LOW	ABS HUMID (grains/ft³)	0.01	W		0.5	0.17	W
HUMIDITY	LOW	DURATION (hours) RELATIVE HUMIDITY (%) AIR TEMPERATURE (°F)	10, 15, 90 ; 5 ; 4, 5, 125 ; 5			W		10, 15, 90 ; 5 ; 4, 2, 160 ; 5 See Note ▲
PRECIPITATION	RAIN	DURATION (hrs: mins) AMOUNT (inches) DROP DIAM (MEAN (mm), STD DEV. (mm)) AIR & WATER TEMP (°F) WIND (mph)	11:55, 12, 2.25, 0.77, 70 ; 00:05, 2, 4.00, 1.60, 70 ; 11:00, 11, 2.25, 0.77, 70, 40 ; 01:00, 7, 3.20, 1.10, 70		W		W	P
PRECIPITATION	SNOW	• EXPECTANCY (days) SNOW LOAD (lb/ft.²)	1, 10 ; 3, 20 ; 150, 40	W				
WIND	10 ft. above surface	• EXPECTANCY (years) ORDINARY (STEADY (mph), GUSTS (mph)) ▲ EXCEPTIONAL (STEADY (mph), GUSTS (mph))	2, 40, 60, 60, 90 ; 5, 50, 75, 70, 105 ; 25, 65, 100, 80, 120	W	W	W	85 (75 knots) 115 (100 knots)	P
PENETRATION AND ABRASION	BLOWING SNOW	FLAKE DIAMETER (mm) WIND (mph) AIR TEMPERATURE (°F)	1 to 3, 40, 0	W			W	P
PENETRATION AND ABRASION	BLOWING SAND	GRAIN DIAMETER (mm) WIND AT 5 ft (mph) AIR TEMPERATURE (°F)	0.10 to 0.30, 40, 100			W	W	W
PENETRATION AND ABRASION	BLOWING DUST	GRAIN DIAMETER (mm) DENSITY (grams/cm³) WIND AT 5 ft (mph) AIR TEMPERATURE (°F)	.0001 to 0.01, 6 x 10⁹, 40, 70			W	W	W
PRESSURE	MAXIMUM		1,060 mb = 31.30 in. = 15.40 lb/in²	W	W	W	W	W
PRESSURE	MINIMUM		505 mb = 14.94 in = 7.35 lb/in²	W	844 mb = 24.85 in = 12.20 lb/in²	844 mb	887 mb = 26.18 in = 12.90 lb/in²	375 mb = 11.1 in. = 5.45 lb/in²

Environmental Protection Branch
Research & Development Division

• Expectancies Vary with Type of Equipment

TYPE	SNOW	WIND
Portable	1 day	2 years
Temporary	3 days	5 years
Semi-permanent	150 days	25 years

W = Same as Operation, Ground, World-wide
P = Same as Operation, Ground, World-wide for Packaging only
→ = Change at uniform rate from preceding to following condition
▲ = Equipment for Exceptional Windy Areas requires auxiliary kits to permit withstanding indicated winds.
▲ = Additional Low Humidity Storage: 30 days at 50°F and ½ % Relative Humidity (Simulating Arctic Storage).

FIGURE 3.6 WEATHER DATA*

TEMPERATURE EXTREMES

United States

Lowest temperature	- 70°F	Rodgers Pass, Montana (January 20, 1954)
Highest temperature	134°F	Greenland Ranch, Death Valley, California (July 10, 1933)

Alaska

Lowest temperature	- 76°F	Tanana (January, 1886)
Highest temperature	100°F	Fort Yukon (June 27, 1915)

World

Lowest temperature	- 90°F	Oimekon, Siberia (February, 1933)
Highest temperature	136°F	Azizia, Libya, North Africa (September 13, 1922)
Lowest mean temperature (annual)	- 14°F	Framheim, Antarctica
Highest mean temperature (annual)	86°F	Massawa, Eritrea, Africa

PRECIPITATION EXTREMES

United States

Wettest state	Louisiana -- average annual rainfall 57.34 inches
Dryest state	Nevada -- average annual rainfall 8.60 inches
Maximum recorded	Camp Leroy, California (January 22-23, 1943) -- 26.12 inches in 24 hours
Minimums recorded	Bagdad, California (1909-1913) -- 3.93 inches in 5 years
	Greenland Ranch, California — 1.76 inches annual average

World

Maximums recorded	Cherropunji, India (July, 1861) — 366 inches in 1 month. (Average annual rainfall of Cherrapunji is 450 inches)
	Bagui, Luzon, Philippines (July 14-15, 1911) -- 46 inches in 24 hours
Minimums recorded	Wadi Halfa, Anglo-Egyptian Sudan and Aswan, Egypt are in the "rainless" area; average annual rainfall is too small to be measured

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* Compiled from "Climate and Man," Yearbook of Agriculture, U. S. Dept. of Agriculture, 1941. Obtainable from Superintendent of Documents, Government Printing Office, Washington 25, D. C.

FIGURE 3.6 WEATHER DATA (cont.)

WORLD TEMPERATURES

Territory	Maximum °F	Minimum °F
North America		
Alaska	100	-76
Canada	103	-70
Canal Zone	97	63
Greenland	86	-46
Mexico	118	11
U.S.A.	134	-70
West Indies	102	45
South America		
Argentina	115	-27
Bolivia	82	25
Brazil	108	21
Chile	99	19
Venezuela	102	45
Europe		
British Isles	100	4
France	107	-14
Germany	100	-16
Iceland	71	- 6
Italy	114	4
Norway	95	-26
Spain	124	10
Sweden	92	-49
Turkey	100	17
U.S.S.R. (Russia)	110	-61
Asia		
Arabia	123	35
China	111	-10
East Indies	101	60
French Indo-China	113	33
Asia (contd.)		
India	120	-19
Iraq	125	19
Japan	101	- 7
Malay States	97	66
Philippine Islands	101	58
Siam	106	82
Tibet	85	-20
Turkey	111	-22
U.S.S.R. (Russia)	109	-90
Africa		
Algeria	133	1
Anglo-Egyptian Sudan	126	28
Angola	91	33
Belgian Congo	97	34
Egypt	124	31
Ethiopia	111	32
French Equatorial Africa	118	46
French West Africa	122	41
Italian Somaliland	93	61
Libya	136	35
Morocco	119	5
Rhodesia	112	18
Tunisia	122	28
Union of South Africa	111	21
Australasia		
Australia	127	19
Hawaii	91	51
New Zeland	94	23
Samoan Islands	96	61
Soloman Islands	97	70

FIGURE 3.7 SYNTHETIC WIND SPEED PROFILES [EXCEEDED 1%, 5%, 10%, and 50% OF THE WINTER FOR THE WINDIEST AREA (NORTHEASTERN PART) OF THE UNITED STATES]

Wind velocities and shears are expected to reach critical values in the vicinity of abrupt temperature changes and inversions. High atmospheric pressure gradients are formed mostly in north-south direction due to these temperature phenomena resulting in layers of strong winds. These layers of winds, the so-called jet-streams, represent nothing new or unusual but only the more steady presence of such atmospheric conditions. Generally three jet-streams can be distinguished: the low level jet (1500 ft), tropopause jet (35,000 ft), and high altitude jet (175,000 ft).

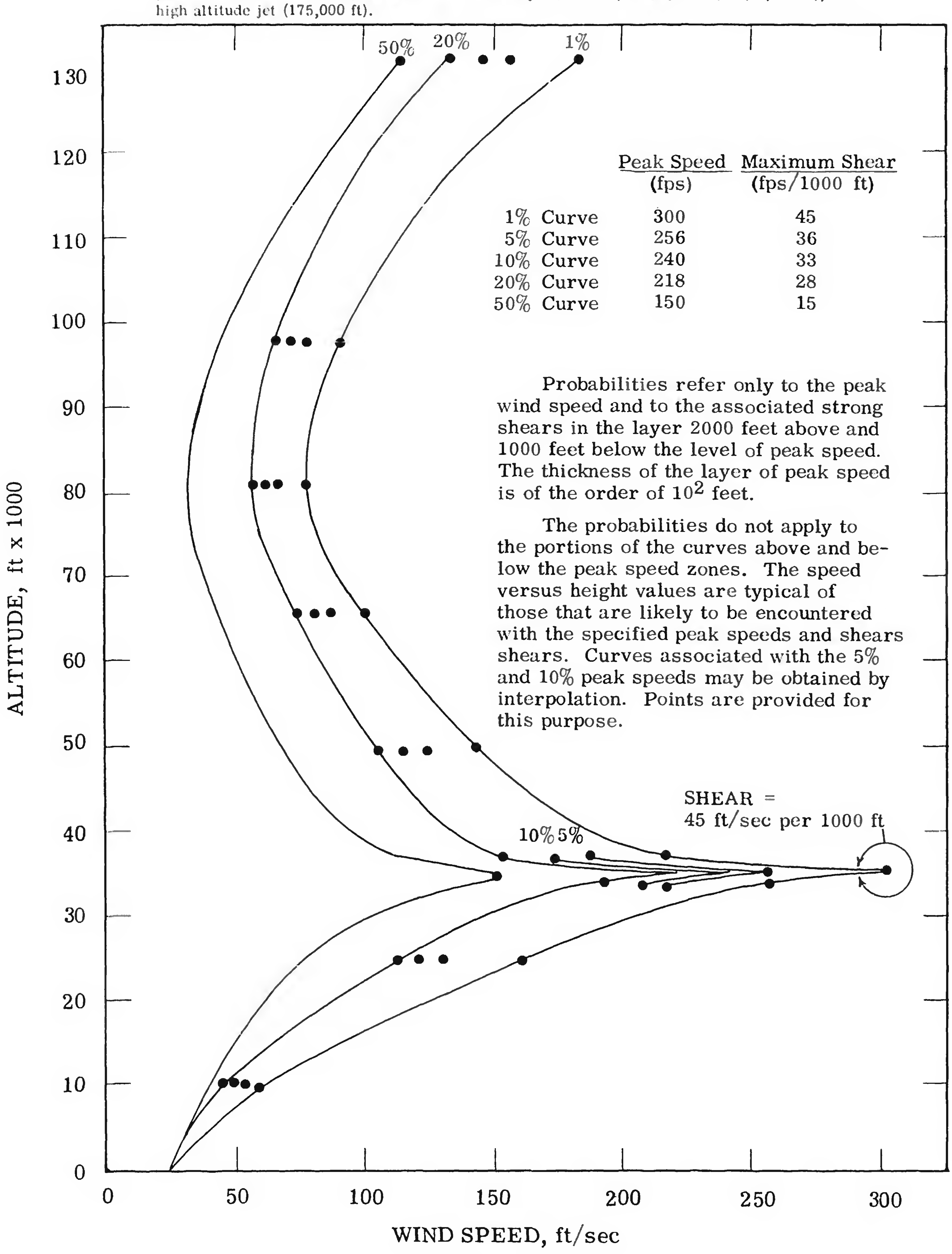


FIGURE 3.8 TYPICAL VIBRATION ENVIRONMENTS

vehicle	range of frequencies in cycles per second	approximate peak amplitude in inches	nature of excitation	usual choice of isolator resonant frequency
Ships	0 to 15	0.02	Engine vibration in diesel or reciprocating steam drive	25 to 30 cycles/second. Most vibrations are amplified to some extent. A maximum amplification of 3 is usually acceptable.
	0 to 20	0.01	Propeller-blade frequency = (propeller rpm) × (number of blades)/60	
Piston-engine aircraft	0 to 60	0.01	Engine vibrations	Above 20 cycles/second. Amplitude of vibrations varies with location in aircraft; landing shock can be neglected
	0 to 100	0.01	Propeller vibrations, aerodynamic vibrations due to buffeting	
Turboprop aircraft	0 to 60	0.01	Engine vibrations = (engine rpm)/60. Also aerodynamic vibrations due to buffeting and turbulence	9 cycles/second
	0 to 100	0.01	Propeller vibrations. Also aerodynamic vibrations due to buffeting and turbulence	
Jet Aircraft	Up to 500	0.001	Audible noise frequencies due to jet wake and combustion turbulence; very little engine vibration	9 cycles/second
Passenger automobiles	1	6	Suspension resonance	25 cycles/second will usually avoid resonance with wheel hop and suspension resonant frequencies
	8 to 12	0.02	Unsprung weight resonance (wheel hop)	
	20+	0.002	Irregular transient vibrations due to resonances of structural members with road roughnesses	
Automobile trucks	4	5	Suspension resonance	Above 20 cycles/second and should not correspond with any structural resonance. It is not advisable to attempt to isolate suspension and unsprung weight resonances
	20	0.05	Unsprung weight resonance	
	80+	0.005	Structural resonances	
Military tanks	1 to 3	2	Suspension resonance	Similar to automobile truck
	Depends on speed	—	Track-laying frequency $\approx 17.6 \dfrac{\text{(speed in mph)}}{\text{(tread spacing in inches)}}$	
	100+	0.001	Structural resonances	
Railroad trains	Broad and erratic		Similar to automobiles with additional excitations from rail joints and from side slop in rail trucks and draft gear	20 cycles/second has been successful in railroad applications. Shock with velocity changes up to 100 inches/second in direction of train occurs when coupling cars or starting freight trains

FIGURE 3.9 SUMMARY OF SPECIFICATION REQUIREMENTS FOR DROP TESTS

Type of Container	Applicable Specification	Weight Classification Gross Weight (lb)	Drop Height (in.)	No. of Drops	Impacting Surfaces	Type of Test
Gen's Spec., Packaging and Packing for Overseas Shipment	JAN-P-100	0-50	30	8	Corners	Free fall
		51-100	24	8	Corners	Free fall
		101-300	42	4	Ends	Table Push-off
		301-600	—	One Revolution	4 Faces	Roll over
		601-Up	—	—	—	Visual inspection
Packaging & Packing for Overseas Shipment, Boxes, Fiberboard (V-Board & W-Board), Exterior & Interior	JAN-P-108	0-160	30	8	Corners	Free fall
Methods of Preservation, " All Military Unit Packages"	MIL'P-116B	0-200 No dimension greater than 60 in.	30	8	Corners	Free fall
		201 and up, or exceeding 60 in. in any dimension	36		Corner	Drop cornerwise
		Dimensions greater than 5 ft.	24		Corner	Drop cornerwise
Gen'l Requirements for Preparation for Delivery of Naval Aeronautical Equipment	MIL-P-7936 (Aer)	0-250, or longest dim. less than 60 in.	30	8	Corner	Free fall
				6	Faces	
		250 and up, or any dimension over 60 in.	36	2	Corner	Drop Cornerwise
Containers, Shipping Reusable, Wood, Aircraft Engines	MIL-C-4116 (USAF)		6, 12, 18, 24, 30, & 36	2	End	Drop edgewise
			6, 12, 18, 24, 30, & 36	4	Corners	Drop cornerwise

Containers, Shipping Reusable, Metal, Aircraft Engines	MIL-C-5584		6, 12, 18, 24, 30, & 36	2	End	Drop edgewise
			6, 12, 18, 24, 30, & 36	2	Corner	Drop cornerwise
Packages containing Missiles or Missile Systems	USAF Specifications Bulletin No. 106	—	24	—	6 faces	Free fall on concrete
Packaging of Guided Missile Weapon System Components (Special Provisions for cylinder shaped packages)	MIL-P-9024A	0-70 Not to exceed 36 in. in any one dimension	30	8	Corners	Free fall on concrete
		70-200 No dimension greater than 60 in.	24	8	Corners	Free fall on concrete
		200-600 No dimension greater than 72 in.	6, 12, 18, 24, 30, & 36	—	Corners	Drop edgewise on crete
		Over 600	6, 18, 18, & 24	--	Corners	Drop edgewise on concrete
		Over 3000	6, 12	--	Corners	Drop edgewise on concrete
Ground Electronic Equipment in the Transit Case	MIL-T-4807 (USAF)	0-90 90-120 120-180 180-Up	4 3 2 1	14	6 faces, 4 edge of cover, & 4 edges of side opposite cover	Free fall on concrete
Ground Support Equipment in Transit Case	MIL-E-4970 (USAF)	1-20 21-50 51-250 250-500 Over 500	42 36 30 24 12	1	3 Mutually Perpendicular faces	Free fall

[Figure 3.9 (cont.)]

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT

Table I – Summary of Shock and Vibration Requirements of Specifications - Airborne

Specification No.	Vibration Requirements	Shock Requirements
MIL-C-172B (Amend 1) (Supersedes JAN-C-172A) Mounting Bases and Isolators	**Fatigue** Cycling -- Vibrate mounted unit at 0.06 in. total excursion from 5-55-5 c.p.s. along each of the 3 principal axes of the unit. Vary frequency uniformly and record all resonant frequencies. (At max. rated load only.) Resonance — Vibrate the mounted unit for 2 hours along each of the 3 principal axes at the predominant resonant frequency for each direction. The spec. limits the magnification at resonance to a maximum of 5. It also states that a resonant frequency should be 15 c.p.s. or less. (At max. rated load only.) **Isolation Efficiency** For this case, see Mil. Specification for detail requirements and tests.	Performance -- The unit with mounts attached shall be subjected to 18 impact shocks of 15 g with a time duration of 11 ± 1 milliseconds. (3 shocks in each of 6 directions.) The mounts should still meet the same vibration performance requirements as before the test. Crash Safety — The unit with mounts attached shall be subjected to 12 impact shocks of 30 g with a time duration of 11 ± 1 milliseconds. (2 shocks in each of 6 directions.) The mounting base and mounts should remain captive.
MIL-E-5400 (Supersedes AN-E-19)	**Equipment With Isolators Attached** Equipment to operate satisfactorily when subjected to continuous vibration at 0.06 in. (D.A.) excursion at any frequency within range of 5-500 c.p.s. and resulting in ±10 g maximum, whichever is limiting value. **Equipment Without Isolators** Equipment to operate satisfactorily when subjected to continuous vibration at 0.01 in. (D.A.) excursion at any frequency within range of 5-500 c.p.s. and resulting in + 2 g maximum, whichever is limiting value.	**Equipment With Mounts Attached** Mounts and equipment to operate after 18 shocks (3 drops in each of 6 directions.) of 15 g with a duration of 11 ± 1 milliseconds. Crash Safety (Mock-up with mounts attached) — Mounts should retain equipment after 12 shocks (2 drops in each of 66 directions) of 30 g with a duration of 11 ± 1 milliseconds. Bending and distortion of mounting base is permitted; however, the base should retain the equipment.

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table I – Summary of Shock and Vibration Requirements of Specifications - Airborne (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-5400 (Supersedes AN-E-19) (cont.)	There is no definite period of time stated in specification for the above 2 tests. We understand that it is intended that the vibration part of this specification is supposed to agree with Procedure XI of Specification MIL-E-5272A.	
MIL-E-5272A General Specification for Environmental Testing of Aeronautical and Associated Equipment	Procedure I Applies to items of equipment mounted directly on structures of aircraft or to equipment mounted directly on gas turbine engines, with or without isolators. (Does not include rocket power aircraft.) Determining Resonance — Vibrate unit at following frequencies by varying frequency slowly over the range given below and determine resonance points along each axis. 5-10 c.p.s. at 0.080 (D.A.) excursion, 10-15 c.p.s. at 0.41 g maximum acceleration, 15-75 c.p.s. at 0.036 (D.A.) excursion, 75-500 c.p.s. at 10 g maximum acceleration. Resonance — The unit will then be vibrated at these resonant points, if any, for the following periods of time along each axis: Room temperature (77°F) - 60 minutes 160°F - 15 minutes -65°F - 15 minutes If more than 2 resonances are encountered along any 1 axis, the test period for that axis may be applied to only the most severe resonance or be divided among the resonances, whichever is considered to produce failure.	Procedure I Applies to items of equipment weighing up to 32 pounds. Test to be conducted on JAN-S-44 shock machine (see specification for details of test.) Equipment Operation 18 shocks (3 drops in each of 6 directions) of 15 g with a duration of 11 ± 1 milliseconds. Crash Safety — The mounts and mounting base shall retain the equipment when subjected to 12 impact shocks of 30 g with a duration of 11 ± 1 milliseconds.

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table – Summary of Shock and Vibration Requirements of Specifications — Airborne (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-5272A General Specification for Environmental Testing of Aeronautical and Associated Equipment (cont.)	If no resonance is apparent along the axis the test for that axis should be 55 c.p.s. at 0.060 in. excursion for twice the period of times specified above. Cycling (Units with vibration isolators attached) Cycle unit from 10-55-10 c.p.s. in 1 minute cycles at 0.060 in. (D.A.) total excursion along each of the 3 axes. The procedure is to be as follows: Room temperature (77°F) – 60 minutes 160°F – 15 minutes -65°F – 15 minutes Cycling (Units without isolators) Cycle unit from 10-500-10 c.p.s. in 15 minutes cycles at 0.036 in. (D.A.) excursion or an applied acceleration of ±10 g, whichever is limiting value. Cycle unit along all 3 axes. The procedure followed is to be as above.	
	Procedure II This procedure applied to items of equipment which mount directly to reciprocating engines with or without isolators. Determining Resonance — Vibrate unit along its 3 mutually perpendicular axes and determine resonant points. The spectrum is as follows: 5-10 c.p.s. at 0.100 in. (D.A.) excursion, 10-14 c.p.s. at 0.51 g maximum acceleration, 14-85 c.p.s. at 0.060 in. (D.A.) excursion, 85-500 c.p.s. at 20 g maximum acceleration.	

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table I – Summary of Shock and Vibration Requirements of Specifications - Airborne (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-5272A General Specification for Environmental Testing of Aeronautical and Associated Equipment (cont.)	Resonance — If resonant frequencies are encountered vibrate the unit for 4 hours at the resonant frequency and at the amplitude given above. The time is 4 hours on each axis. If more than 1 resonance is found on any axis, divide time for that axis between them, or vibrate at worst condition, whichever is most likely to produce failure. If no resonant frequencies are found, vibrate unit for 12 hours along each axis at 0.018 in. (D.A.) excursion and at a frequency of 150 c.p.s.	
	Procedure III This procedure applies to components of equipments that use vibration isolators under the assembled equipment. Determining Resonances — Vibrate component along its 3 mutually perpendicular axes and determine resonant points. The frequency spectrum is as follows: 5-7.5 c.p.s. at 0.500 in. (D.A.) excursion, 7.5-55 c.p.s. at 1.5 g maximum acceleration. If resonant frequencies are found, vibrate the unit for 4 hours at the resonant point at the excursion given above. The time is to be 4 hours for each axis. If more than 1 resonance is found on any axis, divide time for that axis between the resonance or vibrate at worst condition, whichever is most likely to cause failure. If no resonance is found, vibrate for 12 hours along each axis at 0.010 in. (D.A.) excursion at 50 c.p.s. (The above frequencies and excursions are for linear motion. If a circular motion table is used, consult specification for procedure to follow.)	Procedure III Applies to items of equipment weighing over 100 pounds. Test to be conducted on Navy type High Impact machine in accordance with Specification MIL-S-901

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table I – Summary of Shock and Vibration Requirements of Specifications – Airborne (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-5272A General Specification for Environmental Testing of Aeronautical and Associated Equipment (cont.)	Procedures IV, V, VI, VII and VIII (Please consult specification for details)	
	Procedure IX This procedure is used to determine the efficiency of vibration isolation systems at room temperature. The procedure is as follows: Vibrate mounted equipment along its 3 mutually perpendicular axes from 5-55 c.p.s. at 0.036 in. (D.A.) excursions. Measure amplitude of mounted eequipment. The resonant points shall be 15 c.p.s. or less and system should be at least 65% efficient above 26 c.p.s.	
	Procedure X This procedure applies to items of electric equipment (including vibration isolators) which mount directly on the structure of aircraft powered by reciprocating, turbojet, or turbo-propeller engines. Durability – Cycle entire unit from 10-55-10 c.p.s. at 0.03 in. (D.A.) excursion. The cycling time to be between 1-5 minutes. Vibrate for 2 hours along each of the 3 major axes of the unit. Performance -- Vibrate unit from 20-60 c.p.s. at 0.03 in. (D.A.) excursion and 60-200 c.p.s. at 10 g maximum acceleration. The unit shall show no signs of instability or harmful arcing.	
	Procedure XI Equipment Normally Mounted -- Mount the equipment on the	

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table I – Summary of Shock and Vibration Requirements of Specifications - Airborne (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-5272A General Specification for Environmental Testing of Aeronautical and Associated Equipment (cont.)	vibration table. The mounting should simulate service installation including all vibration mounts and other holding devices if any. Then follow the procedures listed below: Step 1 – With the equipment operating, vibrate it in a horizontal direction with the frequency varying between 10 and 55 c.p.s. at an amplitude of 0.03 in. (0.06 in. total excursion). The frequency shall change uniformly from 10 to 55 cycles and return to 10 cycles in from 1 to 3 minutes. This test shall continue for at least 90 minutes and during this time the frequency of any and all resonant points (natural periods) shall be noted. Step 2 – Vibrate the equipment for 15 minutes at each of the resonant frequencies noted in Step 1 at 0.06 in. (D.A.) total excursion. Step 3 – Repeat Steps 1 and 2 changing the direction of vibration 90 degrees horizontally. Step 4 – Repeat Steps 1 and 2 changing the direction of vibration to vertical. Step 5 – Remove the equipment from the table and visually inspect for any mechanical failures. Equipment with Vibration Isolators Removed Mount the equipment directly to the vibration table with vibration isolators removed but including any other required holding device. Then follow the procedures listed below:	

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table I – Summary of Shock and Vibration Requirements of Specifications - Airborne (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-5272A General Specification for Environmental Testing of Aeronautical and Associated Equipment (Cont.)	Step 1 – With the equipment operating, vibrate it in a horizontal direction with the frequency varying between 5 and 500 c.p.s. The total amplitude shall be 0.01 in. or an applied vibratory acceleration of ±5g, whichever is the limiting value. The frequency cycle may be continuous from 5 to 500 or may be in steps. However, the rate of change shall be such that a complete cycle will consume approximately 15 minutes. The test shall continue for at least 2 hours and resonances shall be noted. Step 2 – Vibrate the equipment for 30 minutes at each of the resonant frequencies noted in Step 1. Step 3 – Repeat Steps 1 and 2 changing the direction of vibration 90 degrees horizontally. Step 4 – Repeat Steps 1 and 2 changing the direction of vibration to vertical. Step 5 – Remove the equipment and visually inspect for any mechanical failures.	
MIL-T-5422C (ASG) Testing, Environmental Aircraft Electronic Equipment	Vibration requirements of this specification are identical to Procedure XI of MIL-E-5272A	Shock requirements of this specification are identical to Procedure II of MIL-E-5272A

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table I – Summary of Shock and Vibration Requirements of Specifications - Airborne (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-5009A (Amend. 1) Engines, Aircraft, Turbojet, Qualification Tests For (The vibration and shock tests listed are for all electrical components of the engine)	Vibration — (all components which are not mounted on the engine). Procedure — The test specimen shall be mounted in a manner dynamically similar to its mounting during service use. Resonant frequencies of the specimen or its component parts, shall be determined by vibrating the specimen throughout the frequency range of 5 to 150 c.p.s. in each of 3 mutually perpendicular planes. The frequency spectrum is as follows: 5-14 c.p.s. at 0.500 in. (D.A.) excursion, 14-150 c.p.s. at 5 g maximum acceleration. The specimen shall then be vibrated for 4 hours at each resonant frequency in the plane of resonance. Each test specimen shall be vibrated for a minimum total time of 12 hours in each plane. If less than 3 resonant points are found in any one plane, the additional vibration required shall be accomplished at either a resonant point or at a frequency between 15 and 20 c.p.s. Where practicable, the test specimen shall be made to cycle through its normal range of operation during vibration testing.	Impact — Components shall be subjected to 24 impact shocks of at least 30 g for a time duration of not less than 10 milliseconds. 12 shocks shall be applied directly to the component without shock mounting or shock isolators in place. 12 shocks shall be applied to the component through its normal mounting. In each group above, 2 shocks shall be applied in each of 3 mutually perpendicular axes.

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table I – Summary of Shock and Vibration Requirements of Specifications - Airborne (cont.)

Specification No.	Vibration Requirements	Shock Requirements
Radio Technical Commission for Aeronautics, Washington, D. C. Environmental Test Procedures Airborne Radio Equipment Paper 50-51/DO-44	Vibration Test 1. (a) Secure the equipment to a vibration table by the mounting means intended for use in service installations. Vibration spectrum is as follows: Amplitude: 0.030 in. (0.060 total excursion) Frequency: Variable 10-55 c.p.s. Direction: Parallel to the longitudinal axis of the equipment (b) Vary the frequency slowly through the range of 10-55 c.p.s. and carefully observe the operation of the equipment. (c) Vary the frequency uniformly from 10-55 c.p.s. and returning to 10 c.p.s. in from 1 to 3 minutes. Tests 1(b) and 1(c) shall occupy a minimum total vibration time of 90 minutes with at least 15 minutes devoted to 1(c). 2. Repeat the procedures specified in Paragraphs 1(a), 1(b), and 1(c) with the vibratory motion applied in a direction parallel to the lateral axis of the equipment. 3. Repeat the procedures specified in 1(a), 1(b) and 1(c) with the vibratory motion applied in a direction parallel to the vertical axis of the equipment.	Shock Test 1. Secure the equipment to a shock table by the mounting means intended for use in service installations. Apply to the shock table, with the equipment mounted in each of the following positions in the order listed, 3 shocks each having a peak acceleration of at least 15 g and a time duration of at least 10 milliseconds. (a) Normal upright. (b) Suspended upside down. (c) At an angle such that the major horizontal axis of the equipment forms an angle of 45° with the plane of the table. (d) At an angle such that the minor horizontal axis of the equipment forms an angle of 45° with the plane of the table. 2. Apply, in each of the equipment positions listed in Paragraph 1 above in the order listed, 1 shock having a peak acceleration of at least 30 g and a time duration of at least 10 milliseconds. A mock-up should be used for this test. If desired, a separate equipment unit may be used during the application of each shock.

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table II – Summary of Shock and Vibration Requirements of Specifications - Mobile and Miscellaneous

Specification No.	Vibration Requirements	Shock Requirements
MIL-T-945A (Amend. 2) (General requirements for the design and manufacture of test equipment used in testing of electronic equipment) (Equipment is non-operating during vibration test.)	Variable Frequency Vibration Test — The test set, with and without its transit case or in its combination case, shall be mounted on the vibration table and subjected to the following tests: Test 1 – Cycle table from 10-33-10 c.p.s. in 1/2 minute at a total excursion of 0.06 in. Test 2 – Cycle table from 10-55-55-10 c.p.s. in 1 minute at a total excursion of 0.03 in. The above 2 tests should be conducted along these 3 mutually perpendicular axes of the equipment for 15 minutes along each axis. Fixed Frequency or Final Vibration Test — The test set shall then be vibrated for a period of 3 minutes at each of the 4 most severe resonant frequencies. The excursion of the vibration table is to be the same as that at which the resonance was observed to give the most severe reaction.	Shock Test — Navy High-Impact shock machine for light weight equipment is used for these tests. Portable test sets shall be secured to the machine by means of canvas straps. If a transit case is provided the test set shall also be tested in the transit case. Test Procedure — A total of 9 blows shall be applied parallel to each of the 3 principal axes of the test set being tested. The height of hammer drop for the back and side blow shall be 1, 2 and 3 feet. For the top blow, the height of hammer drop shall be 2, 3 and 4 feet.
MIL-T-4807 (USAF) (Amend. 1) Tests: Vibration and shock Ground Electronic Equipment (requirements for) This spec. replaces AMC Watson Laboratory Exhibit ENG-237	This specification covers the vibration, high impact shock, drop, bounce, and bench handling tests for completely assembled components and systems of ground electronic equipment. The specification is very extensive and it is impossible to summarize it. It is suggested that people interested in this specification obtain copies from Wright Field.	

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table III – Summary of Shock and Vibration Requirements of Specifications - Navy Shipboard

Specification No.	Vibration Requirements	Shock Requirements
MIL-T-17113 (Ships) (Amend. 1) (Supersedes 40T9) Shock, vibration and inclination tests for electronic equipment.	Test procedure – Tests shall be performed in the following order: 1. Inclination test -- Inclination tests shall be made on any device capable of performing the following tests: The equipment shall be inclined at the rate of 5 to 7 c.p.s. in 1 plane to angles of 45° on either side of the vertical for a period sufficiently long to determine its electrical characteristics under such motion or for a minimum of 30 minutes. The test shall then be repeated with the equipment reoriented 90° to the plane in which it was originally tested. 2. Vibration tests Determination of resonances Secure the unit under test to vibration table and vibrate at frequencies of from 33 to 5 c.p.s. at a total excursion of 0.010 in. This test is to be conducted along the 3 mutually perpendicular axes of the equipment. Normal vibration test – The unit will be secured to the vibration table and vibrated at frequencies of from 5 to 23 c.p.s. in discrete intervals of 1 c.p.s. At each integral frequency, the vibration shall be maintained for 3 minutes. Tests shall be made with a total table excursion of 0.06 in. This test will be conducted along the 3 mutually perpendicular axes of the equipment.	Shock tests should be conducted after the inclination and vibration tests have been completed for light weight equipment This test is for equipment weighing less than 250 pounds. The shock machine used for this test is the Navy type High Impact shock machine for light weight equipment. The equipment shall be attached to the shock machine and subjected to a total of 9 blows, 3 blows being applied parallel to each of the 3 principal axes of the equipment being tested. The height of hammer drops shall be 1, 2 and 3 feet heights. For medium weight equipment – This test is for equipment weighing over 250 pounds, but less than 4500 pounds (consult the specification for details of this test).

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table III – Summary of Shock and Vibration Requirements of Specifications – Navy Shipboard (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-T-17113 (Ships) (Amend. 1) (Supersedes 40T9) Shock, vibration and inclination tests for electronic equipment (cont.)	Final vibration test – Vibrate the equipment for a total period of 2 hours at any frequency or frequencies between 5 and 23 c.p.s. and along each axis or axes which the previous test showed may be the conditions most likely to cause failure. (This means that the 2 hours vibration time should be divided among the resonant frequencies, if any, or the total period of 2 hours can be applied to any 1 frequency, whichever is more likely to cause failure.) (The total excursion of the vibration table for this test is normally 0.06 in.)	
MIL-T-17113 (Ships) 40T9 (Amend. 2) Tests; Shock, vibration, and inclination (for special equipment)	Vibration and inclination tests same as in MIL-T-17113 (Ships)(Amend. 1) above.	See above also.
MIL-S-901B (Navy) Shock-proof equipment, Class HI (high-impact) shipboard application, tests for	No vibration tests required	For light weight equipment – This is for equipment weighing less than 250 pounds. Navy High Impact shock machine for light weight equipments shall be used for this test. A total of 9 blows shall be applied, 3 blows parallel to each of the 3 principal axes of the equipment being tested. The height of drops will be 1, 3 and 5 feet. For medium weight and heavy weight equipments –(consult the specification for details of shock test).

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table IV – Summary of Shock and Vibration Requirements of Specifications - Packaging

Specification No.	Vibration Requirements	Shock Requirements
MIL-C-5584A (Amendment 1) Covers metal shipping containers for aircraft engines	No vibration requirements on the container. However, the container must protect the engine by provision for vibration isolators.	This specification is very extensive including such types of drops as rotational, edgewise, flatwise, tipover, rollover, and impact. The specification is impossible to summarize in a small space and it is recommended that a copy be obtained for direct reference.
MIL-P-9024A (USAF) General Design Requirements for Packaging of Guided Missile Weapon System Components	Determining Resonance — Vibrate unit along its three mutually perpendicular axes and determine resonance points. The spectrum is as follows: 2-26 c.p.s. at 1.3 g maximum acceleration, 26-55 c.p.s. at 0.036 in. (D.A.) excursion, 55-340 c.p.s. at 5.0 g maximum acceleration. Resonance — If resonant frequencies are encountered, vibrate the unit for 30 minutes at the resonant frequency and at the amplitude given above. The time is 30 minutes on each axis.	This specification is difficult to summarize and it is recommended that reference to the specification be made in this case.
USAF SPECIFICATION Bulletin No. 106 Environment for the Complete Life of a Guided Missile System	Applies to the package for missile equipment. Truck Transportation -- Vertical 200 c.p.s. at 2.5 g, 40 c.p.s. at 1.0 g; Longitudinal 150 c.p.s. at 1.5 g, 10 c.p.s. at 1.0 g; Sidewise 200 c.p.s. at 1.0 g, 10 c.p.s. at 1.0 g. Rail Transportation -- Vertical 60 c.p.s. at 2.0 g, 10 c.p.s. at 1.0 g; Longitudinal 60 c.p.s. at 1.0 g, 10 c.p.s. at 0.5 g; Sidewise 30 c.p.s. at 1.0 g, 10 c.p.s. at 0.5 g. Aircraft Transportation — Vertical 60-100 c.p.s. at 1.0 g, 100-200	Applies to the package for missile equipment. Truck Transportation — 8 g Rail Transportation -- 20 g Aircraft Transportation — Vertical - 5.5 g Side - 1.5 g Longitudinal - 8.0 g Drop Heights -- 24 in. on concrete on all faces.

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table IV – Summary of Shock and Vibration Requirements of Specifications - Packaging (cont.)

Specification No.	Vibration Requirements	Shock Requirements
USAF SPECIFICATION Bulletin No. 106 Environment for the Complete Life of a Guided Missile System (cont.)	c.p.s. at 0.5 g; Longitudinal 60-100 c.p.s. at 1.0 g; Sidewise 60 c.p.s. at 1.0 g, 100 c.p.s. at 0.5 g. Ships Transportation – Vertical 10 c.p.s. at 0.5 g, 30 c.p.s. at 1.5 g, Sidewise 10 c.p.s. at 0.25 g, 30 c.p.s. at 0.75 g. Acoustical Noise Level – 90-130 db above 10^{-16} watts/cm^2.	

Table V – Summary of Shock and Vibration Requirements of Specifications - Ground Equipment

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-4158A (USAF) (Amend. 1) General Requirements for design of Ground Electronic Equipment	Shock and vibration isolators shall not be used unless it is impracticable to design without their use. If used, the amplitude shall not be more than 3 times the amplitude of the applied vibration from 10-20 c.p.s. and not more than 6 times the amplitude of the applied vibration from 20-55 c.p.s.	
MIL-E-4970 (USAF)	Procedure I Applies to equipment installed on vehicles and expected to be operating. (Restricted to smooth surfaced areas or first class roads.) Determining Resonance – Vibrate unit from 2 to 300 c.p.s. at ± 1.3 g by varying frequency slowly over the range and determine resonance points along each axis. The unit will then be vibrated at these resonance points, if any, for the following periods of time along each axis. Room temperature (77°F) - 60 minutes 160°F - 15 minutes - 65°F - 15 minutes	Procedure I Equipment - Non-Operating – 9 shocks (3 shocks along each of 3 perpendicular directions) of 10 g with a duration of 11 ± 1 milliseconds.

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table V – Summary of Shock and Vibration Requirements of Specifications - Ground Equipment (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-4970 (USAF) (Cont.)	If more than 2 resonances are encountered along any 1 axis, the test period for that axis may be applied to only the most severe resonance or be divided among the resonances, whichever is considered to produce failure. If no resonance is apparent among the axis the test for that axis should be 55 c.p.s. at ±4 g acceleration for twice the period of times specified above. Cycling — Cycle unit from 25-250-25 c.p.s. in 15 minute cycles at ±1.3 g acceleration along each of the 3 axes. Room temperature (77°F) – 160°F - 60 minutes 160°F - 15 minutes - 65°F - 15 minutes	
	Procedure II This procedure applies to items of equipment which are installed on vehicles and expected to be operating. (Will operate on secondary or unimproved roads and cross-country conditions.) Determining Resonance — Vibrate unit along its 3 mutually perpendicular axes and determine resonance points. The spectrum is as follows: 2-3 cycles at 9 in. (D.A.) excursion, 3-300 c.p.s. at ±4 g acceleration. Resonance — If resonant frequencies are encountered vibrate the unit for 3 hours at the resonant frequency and at the amplitude given above. The time is 3 hours on each axis. If more than 1 resonance is found on any axis, divide time for that axis	

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table V - Summary of Shock and Vibration Requirements of Specifications - Ground Equipment (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-4970 (USAF) (cont.)	between them, or vibrate at worst condition, whichever is most likely to produce failure. If no resonant frequencies are found, vibrate unit for period twice as long as those given at a frequency of 55 c.p.s. and an acceleration of ±4 g. Cycling — Cycle unit from 25-250-25 c.p.s. in 15 minute cycles. Vibration shall be applied for one hour along each of 3 axes and the acceleration shall be the maximum specified for the resonance survey.	
	Procedure III	Procedure II & III
	This procedure applies to components of equipment to be shipped by all modes of carriers. (If shipment case is provided, it must be in test setup.)	
	Determining Resonance — Vibrate component along its 3 mutually perpendicular axes and determine resonant points. The frequency spectrum is as follows: 2-27.5 c.p.s. at ± 1.3 g maximum acceleration, 27.5-52 c.p.s. at 0.036 in. (D.A.) excursion, 52-500 c.p.s. at ± 5 g maximum acceleration. Resonance — If resonance frequencies are found, vibrate the unit for 30 minutes at the resonant point at the excursion given above. The time is to be 30 minutes for each axis. If no resonance is found, vibrate for 3 hours along each axis under the cycling conditions given below. Cycling — Cycle unit from 10-500-10 c.p.s. in a 15 minute interval. The frequency spectrum is as follows: 10-53 c.p.s. at 0.036 in. (D.A.) excursion, 53-500 c.p.s. at	Shock Testing — 18 shocks (3 shocks on each of 6 sides of the case) of 20 g with a duration of 11 ± 1 millisecond. Drop Testing — One drop on each of 3 mutually perpendicular faces. Height of drop depends on weight, as follows: 0 - 20 lbs. 42 in. 21 - 50 lbs. 36 in. 51 - 250 lbs. 30 in. 250 - 500 lbs. 24 in. Over - 500 lbs. 12 in.

[Figure 3.10 (cont.)]

FIGURE 3.10 SUMMARY OF SPECIFICATION REQUIREMENTS FOR SHOCK AND VIBRATION FOR AIRBORNE EQUIPMENT (cont.)

Table V – Summary of Shock and Vibration Requirements of Specifications – Ground Equipment (cont.)

Specification No.	Vibration Requirements	Shock Requirements
MIL-E-4970 (USAF) (cont.)	± 5 g acceleration. Subject specimen to 3 cyclic variations (45 min.) along all 3 axes.	
	Procedure IV For vehicle type (self-propelled) of equipment, the unit shall be transported 5 times over the following test courses: Coarse washboard (6 in. waves spaced 72 in.) 3 - 5 mph Belgian blocks 15 - 20 mph Radial washboard (2 in. to 4 in. waves) 12 - 15 mph Single corrugations (4 in. waves) 15 - 20 mph Short sections between above sections - 20 mph	
	Procedure V For all vehicles (including non-self-propelled), tests shall be in accordance with MIL-M-8090 for Type I and Type II mobility.	
	Procedure VI The following tests are to determine the ability of bench serviced equipment to withstand the shock encountered during servicing (chassis and front panel assembly shall be removed and placed on a solid bench top): (a) Using all practical edges of the horizontal face as pivots, tilt up so the back edge is 4 in. from table and permit to drop freely. (b) Repeat (a) with the unit on other faces for a total of 4 times on each face.	

FIGURE 3.11 SUMMARY OF SPECIFICATION REQUIREMENTS FOR TEMPERATURE TESTS

Specifications	High Temperature Design and Tests	Low Temperature Design and Tests	Temperature Shock Design and Test
Mil-E-5272A Aeronautical and associated equipment	Procedure I Equipment to operate satisfactorily at 160° F after 160° F for 50 hours	Procedure I Equipment to operate satisfactorily at -65° F after stabilization at -65° F. Procedure II Equipment to operate satisfactorily at -65° F after being cooled to -80° F for 48 hours and raised to -65° F for 24 hours	Procedure I Equipment to operate satisfactorily at room temp after 3 cycles of 185° F for 4 hours and transferred in 5 minutes to -40° F for 4 hours Procedure II Equipment to operate satisfactorily at room temp. after operating at 77° F for 1 hour, -67° F for 1 hour, and 160° F for 1 hour
Mil-E-4970(USAF) Ground Support Equipment (Test Requirement)	Procedure I (Unsheltered) Equipment to operate satisfactorily at 160° F after 160° F for 50 hours	Procedure I (Unsheltered in Low Temperature Area) Equipment to operate satisfactorily at -65° F after being cooled to -80° F for 48 hours and raised to -65° F for 24 hours	NONE

[Figure 3.11 (cont.)]

	Procedure II (Sheltered) Equipment to operate satisfactorily at 125° F after 125° F for 50 hours	Procedure II (Unsheltered in Temperate Areas) Equipment to operate satisfactorily at -40°F after being cooled to -80°F for 48 hours and raised to -40°F for 24 hours Procedure III (Sheltered in Temperate Areas) Equipment to operate satisfactorily at 32°F after being cooled to -80°F for 48 hours and raised to 32°F for 24 hours	NONE
USAF Specification Bulletin #106 Guided Missile Systems Ground Operations	Non-Operating 160°F for 4 hours Operating 125°F for 4 hours	Non-Operating -80° F for 3 days Operating Ambient temperatures at altitudes from 0 to 100,000 feet	NONE
Mil-STD-210 Military Equipment	(1) Ground World-Wide 125°F plus 105 Watts/sq. ft. for 4 hrs. (2) Ground, Moist Tropics 90°F plus 90 Watts/sq. ft. for 4 hrs.	(1) Ground World-Wide -65°F & 5 mph Wind for 72 hours (2) Ground, Arctic Winter -65°F & 5 mph Wind for 72 hours	NONE

FIGURE 3.11 SUMMARY OF SPECIFICATION REQUIREMENTS FOR TEMPERATURE TESTS (cont.)

Specifications	High Temperature Design and Tests	Low Temperature Design and Tests	Temperature Shock Design and Tests
Mil-STD-210 Military Equipment (cont.)	(3) Ground, Hot Desert 125°F plus 105 Watts/sq. ft. for 4 hrs. (4) Shipboard, World-Wide 100°F plus 90 Watts/sq. ft. for 4 hrs. (5) Short Term Storage 160°F for 4 hours	(3) Shipboard, World-Wide -20°F & 40 kn. Wind for 24 hours (4) Short Term Storage -80°F & No Wind for 24 hours	
Mil-E-5009A Turbojet Aircraft Engines	Each test assembly or component to operate satisfactorily at 200°F after 200°for 1 hour	Each assembly or component to operate satisfactorily at -65°F after -65°F for 72 hours	NONE
Mil-E-5400A (ASG) & Mil-T-5422C (ASG) Aircraft Electronic Equipment Class 1 - S.L. to 50,000 feet altitude Class 2 - S.L. to 70,000 feet altitude	(1) Continuous Operation Class 1 equipment to operate satisfactorily at 130°F Class 2 equipment to operate satisfactorily at 160°F (2) Intermittent Operation Class 1 equipment to operate satisfactorily at 160°F for 30 minutes Class 2 equipment to operate satisfactorily at 203°F for 30 minutes (3) Non-operating Equipment to operate satisfactorily after being at 185°F for a long period	(1) Continuous Operation Class 1 & 2 equipment to operate satisfactorily at -67°F after long period at -67°F (2) Intermittent Operation Class 1 & 2 equipment to operate satisfactorily at -67°F for 30 minutes (3) Non-operating Equipment to operate satisfactorily after being at -80°F for long period	NONE

Mil-H-5440B Aircraft Hydraulic Systems	Type I equipment to operate satisfactorily at 160°F Type II equipment to operate satisfactorily at 275°F Type III equipment to operate satisfactorily at 400°F	Type I, II and III, equipment to operate satisfactorily at -65°	NONE
Mil-P-5518A Aircraft Pneumatic Systems	Equipment to operate satisfactorily at 160°F	Equipment to operate satisfactorily at -65°F	NONE
Mil-E-8189A (ASG) Guided Missile Electronic Equipment	Equipment to operate satisfactorily at 136°F	Equipment to operate satisfactorily at 36°F	NONE
Mil-G-008512A (USAF) Ground Support Equipment (Design Requirements)	Test Methods Same as Mil-E-4970 (USAF)	Without External Heat Equipment to operate satisfactorily at -20°F With External Heat Equipment to operate satisfactorily between -65°F and -20°F Test Methods Same as Mil-E-4970	NONE
Mil-M-8555 Guided Missiles	All guided Missiles to operate satisfactorily at 160°F	All guided missiles to operate satisfactorily at -65°F	NONE
Mil-P-9024A (USAF) Guided Missiles Weapon System Packaging	Test Same as Mil-E-5272	Test same as Mil-E-5272	

FIGURE 3.12 COMPONENT SELECTION FOR ENVIRONMENTAL CONDITIONS*

With variations in the degree of complexity, the performance of a missile or assembled equipment depends directly upon the performance of all its component parts. In turn, the performance of the equipment and each of its parts is affected by environment factors.

To achieve satisfactory performance, therefore, the overall missile and each component must be designed or selected for a specific function and protected to assure operation when exposed to environmental factors.

Environment is frequently interpreted to mean only conditions of weather, temperature, humidity, or the presence of dust and grime. However, if the device is supplied with power, then this power is part of the environment and any changes or impurities in it must be considered, as must conditions of sunshine, tropical environment and internally generated conditions of heat or vibration.

In the evaluation of component parts the general rule of Table B should be followed. Component evaluation and determination of this type assures a minimum need for equipment redesign as a result of environmental malfunctioning.

Continual inspection tests on component parts before they are finally assembled into the equipment prevents expensive rework after assembly. Defective or below average parts can be rejected. Table C indicates the inspection tests for some components.

Environmental performance is an essential part of reliability. The knowledge of what defects may occur to components under various environmental conditions will help to improve component and system design and protection. Table D indicates the proper application techniques for selected protective devices. Table E lists the various environmental conditions, defects and remedies.

* The Tables are from an article by the same name by A. H. Koppel; published in PRODUCT DESIGN HANDBOOK ISSUE, PRODUCT ENGINEERING., October 1955.

FIGURE 3.12 COMPONENT SELECTION FOR ENVIRONMENTAL CONDITIONS (cont.)

TABLE A — TYPES OF SPECIFICATIONS

No.	Specification	Typical Items Covered
I	Performance (What shall the equipment do) (What tolerances are imposed on the performance requirements)	Type of output function Accuracy of output Number of operations (active life) Storage life (idle life) Power level of output (with tolerances) Power level of input (with tolerances) Type of input
II	Environment (Where shall the equipment perform) (Within what tolerances shall it perform in the specified environment)	Weather conditions (humidity, temperature, pressure) Type of input power Local physical donditions (corrosive atmosphere, presence of oil, grease, dirt, dust) Radiation (sunlight, electro-magnetic) Mechanical conditions (acceleration, vibration, shock, sliding motion)
III	Major Specifications (What are the minimum performance requirements that are expected of the type of device)	Local, country, and state laws Federal agency regulations Underwriters' requirements Contractural requirements
IV	Minor Specifications (What special design limitations are imposed)	Customer maintenance specifications Customer component specifications Customer material specifications

TABLE B — EVALUATION OF COMPONENT PARTS

1 — Determine the functional requirements and establish tolerances.

2 — Study available components that meet the functional requirements for compliance with the specifications.

3 — Conduct evaluation tests to establish adherence to performance and environmental requirements.

4 — Initiate modification, where necessary, to assure adherence to all requirements. If a component cannot be modified, equipment or specification changes are made.

5 — Select supplemental components or finishes to act as protective devices.

6 — Conduct evaluation tests on the supplemental components for adherence to the specifications.

FIGURE 3.12 COMPONENT SELECTION FOR ENVIRONMENTAL CONDITIONS (cont.)

TABLE C - TYPICAL COMPONENT INSPECTION AND TEST CLASSIFICATION

Item	Inspect For	Class of Test	Frequency
Wire	Pinholes in insulation - Dielectric strength - Tensile strength and elongation	Nondestructive	Sampling of footage from each roll
Thermostats	Contact continuity - Hipot - Temperature setting	Nondestructive	100 per cent
Shock mounts	Deflection at rated load - Resonant frequency	Nondestructive	Sampling
Fuses	Blow-current – Blow-time	Destructive	Sampling
Structural parts	Faults by X-ray or super-sonic test	Nondestructive	100 per cent
Vacuum tubes	Filament current - Inter-element leakage - Inter-element shorts - Emission	Nondestructive	100 per cent
Hermetically sealed parts (low pressure)	Water immersion by change in weight	Nondestructive	100 per cent
Hermetically sealed parts (atmospheric or higher pressure)	Immersion in water and detergent for bubble test, or mass-spectrometer for higher accuracy	Nondestructive	100 per cent
Moving parts	Friction	Nondestructive	Sampling
Motors	Starting voltage - Current surge - Speed - Dielectric strength - Torque	Nondestructive	100 per cent

FIGURE 3.12 COMPONENT SELECTION FOR ENVIRONMENTAL CONDITIONS (cont.)

TABLE D — TYPICAL USES OF PROTECTIVE DEVICES

If Design Calls For	To Protect against	Use
Hermetic sealing	Overheating of electrical equipment	Ventilation through sealed ducts. Heat sinks.
Encapsulation	Overheating of electrical equipment	Encapsulating materials that are good heat conductors.
Ventilation	Insufficient cooling	Provision for strong turbulence around heat generating equipment. Properly rated blowers. Avoid free spaces where turbulence can dissipate itself. Properly designed air intakes and exhauses. Air Filters.
Finish by plating or painting	Peeling of finish	Primers, and properly prepared surfaces. Proper intersurface plating between incompatible metals. Sufficient thickness.
Shock or vibration mounts	Damage to mount	Proper mounting provisions to prevent "break-away". Proper rating to prevent bottoming. Proper finish to prevent corrosion and fungus growth.
Heaters	Overheating	Provide thermostatic control.
Interference filters	Malfunctioning of the equipment	Properly rated filter that has a specified maximum line drop.

FIGURE 3.12 COMPONENT SELECTION FOR ENVIRONMENTAL CONDITIONS (cont.)

TABLE E — EFFECT OF ENVIRONMENT ON COMPONENT DESIGN

Items	Shock and Acceleration	Vibration
Mechanical: Moving parts, Structures, Fasteners	Effect — Pins may bend or shear - Pins and reeds deflect - Shock mounts may break away from mounting base - Mating surfaces and finishes may be scoured. Remedy — Design for proper strength - Use proper shock mounts.	Effect — If resonant frequency of item is near frequency of vibration, there can be material fatigue, resulting in fracture - Movable parts, such as screws and pins may be displaced - Liquids are subject to cavitation and turbulence. Remedy — Dampen frequency by use of vibration mounts - Design items so that natural frequency is of different magnitude than expected vibration.
Electronic and Electrical	Effect — Filament windings may break - Items may break away if mounted only by their leads - Normally closed pressure contacts may open - Normally open pressure contacts may close - Closely spaced parts may short. Remedy — Use shock mounts - Use mounting brackets - Use properly rated components	Effect — Natural frequency near forcing frequency can cause breakage of supporting structures, soldered wires, or filaments; chattering of contacts; pointer-type devices may read falsely - Conductors can temporarily short - Changes in crystalline structure of filament and fuse elements may affect operating characteristics. Remedy — Use damping by means of vibration mounts - Use clamps or brackets for mounting - Use properly designed items that are rated for operation of the specified frequency of vibration.
Electromagnetic	Effect — Rating or sliding devices may be displaced - Hinged part may temporarily engage or disengage - Windings and cores may be displaced. Remedy — Use shock mounts - Make sure components are balanced dynamically - Use properly rated components.	Effect — Lead wires may break - Laminations may vibrate - Spring-type contacts may chatter - Improperly balanced rating devices may be set in motion. Remedy — Use vibration mounts - Use properly designed items where the natural frequency is of different magnitude than that of vibration. Use dynamically balanced rotary devices.
Thermally active	Effect — Heater wires may break - Bimetallic strips can bend - Calibration may change.	Effect — Filament wires, lead wires and supporting parts may break - Changes in crystalline structure may affect operational characteristics - Contacts

FIGURE 3.12 COMPONENT SELECTION FOR ENVIRONMENTAL CONDITIONS (cont.)

TABLE E — EFFECT OF ENVIRONMENT ON COMPONENT DESIGN

High Temperature	Low Temperature
Effect — Expansion may cause jamming or loosening - Soldered seams may weaken - Strength and elasticity of parts may change - Lubricants may evaporate or flow - Linkage devices may malfunction or lose calibration. Remedy — Use properly rated materials - Design for proper strength - Use cooling through ventilation or refrigeration.	Effect — Materials will contract - Lubricants may gel - Moving parts may jam because of contractions - Elastic constant and strength will change and moisture may condense forming ice. Remedy — Use properly rated materials - use heaters with thermostatic controls - Provide drain holes.
Effect — Constants of resistance, inductance, capacitance, power factor, dielectric constant and strength, and others will vary - Insulation may soften - Contacts may open or close by warping under expansion - Electrical characteristics which are a function of dimension will change under expansion. Remedy — Use properly rated items - apply proper de-rating - Cool by means of ventilation or refrigeration - Dielectric strength and power dissipation should be de-rated with increasing temperature.	Effect — Plastic and rubber insulation lose flexibility; contraction can cause fissures - Electrical constants will vary - Electrical characteristics which are a function of dimension will change - Moisture condensation may lead to short circuits and ice formations - Pointer-type devices can freeze, or lose calibration - Ice formation may cause non-conductivity of pressure contracts. Remedy — Use properly rated materials - Use heaters with thermostatic control - Place components in a hermetically sealed enclosure which is dry gas filled - Self generated heat after warm-up period can restore characteristics.
Effect — Magnetic characteristics of laminations and core-materials change - Dielectric strength of insulation changes - Rotating devices may jam - Lubricants may flow or evaporate. Remedy — Design for operation at specified temperature - Cool by means of ventilation or refrigeration.	Effect — Magnetic characteristics may change - Lubricants may gel and increase in viscosity causing higher friction - Moisture condensation may cause short circuits - Ice formation can stop moving parts. Remedy — Use hermetically sealed enclosures filled with dry gas - Use heaters.
Effect — If the component is one whose function is to generate heat it can be destroyed - If thermally activated (thermal time delay device) it will lose calibration.	Effect — If component is activated by heat (thermal time delay relay) it may lose calibration - If component is to generate heat it will not be damaged but it must have sufficient generating capacity.

FIGURE 3.12 COMPONENT SELECTION FOR ENVIRONMENTAL CONDITIONS (cont.)

TABLE E — EFFECT OF ENVIRONMENT ON COMPONENT DESIGN (cont.)

Items	Shock and Acceleration	Vibration
Thermally active (cont.)	Remedy — Use shock mounts - Use properly rated components.	may chatter - Threaded base devices can loosen Remedy — Dampen with vibration mounts.
Finishes	Effect — Blisters and cracks may occur. Remedy — Use proper materials and finishes.	Effect — When applied to a bending or flexing member, finish may chip or flake - Rough surfaces will assume a smooth appearance. Remedy — Study characteristics for their affect under vibration and use applicable finish.
Materials	Effect — Under load, materials may bend, shear, or splinter - Glue lines can separate - Welds can break. Remedy — Use shock mounts - Use proper types of materials - Use proper types of joining - Make sure loads are within tolerance.	Effect — Can cause changes in crystalline structure - Solder joints may fail in fatigue and break when vibrated near the resonant frequency. Remedy — Dampen with vibration mounts - Use proper design to make natural frequency different from the forcing frequency.

HUMIDITY

Effect on all items: High humidity implies a high water content in the surrounding atmosphere. This leads to two possible deleterious effects: (a) moist air will penetrate into porous substances, where a reaction between water and other substances may produce low-leakage paths between electrical conductors - Existence of moist air will also produce oxidation, leading to corrosion - Moisture may also cause swelling and expansion in porous, water-absorbing substances, such as gasketing materials. (b) Moisture will condense when the air is cooled - Where condensed water accumulates there will be the same effects as listed in (a) above, but possibly in more accelerated manner - Also see section on salt atmosphere.

Remedy: Mechanical — Use proper finish for materials - Gasketing should be made of non-absorbent material - Lubricated surfaces and assemblies should be sealed - Use of drain holes wherever water may accumulate.

Electronic and Electrical — Use non-porous insulating materials - Impregnate cut edges on plastic with moisture-resistant varnish or resin - Seal components with moving parts - Perforate sleeving over cabled wiring to avoid accumulation of condensed water - Use only pure resin as a flux - Encapsulate or seal.

FIGURE 3.12 COMPONENT SELECTION FOR ENVIRONMENTAL CONDITIONS (cont.)

TABLE E — EFFECT OF ENVIRONMENT ON COMPONENT DESIGN (cont.)

High Temperature	Low Temperature
Remedy — Use properly rated devices and thermal controls - Use proper materials in the construction of the component - Use cooling.	Remedy — Use properly rated components - Design its circuits within possible deviation from calibration.
Effect — Paint may blister - Low-melting point metal plating may peel or blister - Plastic coatings may melt. Remedy — Use properly rated paint - Use electrochemical finishes - Use cooling.	Effect — Materials will generally contract - Plastic flexible materials may become rigid - Lubricant can gel - Liquids become more viscous, and freeze. Remedy - Use appropriate materials - Supply heat from controlled heaters.
Effect — All materials have melting, or softening points - Strength is affected by high temperature. Remedy — Use cooling - Use proper materials - Design for heat conductance.	

Electromagnetic — Impregnate windings with moistureproof varnish. Encapsulate or hermetically seal - Avoid the use of commutators - Provide long creepage distances - Use alumina insulators.

Thermally Active — Use non-hygroscopic materials - Hermetically seal, where possible.

Finishes -- Avoid porosity, do not use very thin "flash" plating - Do not use finishes which corrode easily, or which are water soluble.

Materials — Do not use hygroscopic materials - Do not use porous materials - Impregnate with wax, varnish or resin on all capillary edges.

HIGH ALTITUDE

Effect on all items: high altitude generally means low temperature and pressure - Low pressure causes leaks to appear where there is a pressure differential on hydraulic lines, hermetic enclosures and gasketed connections - Leaks in hermetically sealed assemblies whose internal pressure is 1 atmos. or greater, cause reduced internal pressure at high altitude - A return to sea level then causes entry of possibly moist air - See section on humidity and low temperature.

FIGURE 3.12 COMPONENT SELECTION FOR ENVIRONMENTAL CONDITIONS (cont.)

TABLE E — EFFECT OF ENVIRONMENT ON COMPONENT DESIGN (cont.)

Remedy — See low temperature section of table - Use proper inspection method for sealed assemblies.

SALT ATMOSPHERE

Effect on all items: Three effects are attributed to salt atmosphere. (a) Electrical leakage: dissolution of salts in water generally increases the electrical conductivity of water. Where there is an accumulation of salt water, insulating resistance will decrease. (b) Galvanic couples: salt water causes a weak electrical potential at the boundary between certain metals when adjacent - The existence of this potential cause a current flow and metal corrosion - Degree of corrosion depends upon the materials position in the electrochemical table and upon the surface area of the materials exposed. (c) Chemical reaction: corrosion is accelerated because of the chlorine ion present in the salt atmosphere.

Remedy — Electrical leakage: use long creepage distances, and barriers between terminals - Encapsulate or hermetically seal - Provide drain holes and avoid water traps - Porous substances or capillary materials should be impregnated with varnish or resin. Galvanic couples: do not use incompatible materials - Where this is impossible use a compatible plating on one of the materials. Chemical reaction: use proper paint or plating for protection.

SUNSHINE

Effect on all items: Colors may fade such as color coding of electrical components, or protective coloring - Light intensity, or reflection, may make it difficult to read dials - Ultraviolet radiation may affect the elasticity or flexibility of certain rubber compounds, or plastic materials - It will also cause increased temperature within exposed enclosures.

Remedy — Use properly rated materials - Consider brightness and the adaptability of the human eye in dial design - Use light shields - See section on high temperature.

EXPLOSIVE ATMOSPHERE

Effect on all items: An explosive atmosphere generally is a mixture of hydrocarbon vapors and air, or the presence of natural gas - Such a mixture is easily ignited by sparks, which may be produced by the make and break action of pressure contacts, as well as by improperly made permanent electrical contacts, or by the impact of hard material upon one another.

Remedy — Only safe protection against explosion is hermetic sealing of all items that have sliding or otherwise moving electrical contacts - It is possible to design enclosures that prevent ignition outside even when ignition takes place within -Temperature should be kept below the ignition point at the existing pressure.

TROPICAL ENVIRONMENT

Effect on all items: Tropical environment generally is humid, (see humid section). However fungus spores must be considered - Fungi will feed on organic matter, including wood, paper, cotton, cellulose, etc. - Fungus-inert material will not support a a fungi growth, however a deposit of dust and dirt on the part will - Fungistatic implies

FIGURE 3.12 COMPONENT SELECTION FOR ENVIRONMENTAL CONDITIONS (cont.)

TABLE E – EFFECT OF ENVIRONMENT ON COMPONENT DESIGN (cont.)

the presence of a substance which is injurious to fungi, or a fungacide - Fungicides should be selected with caution from a viewpoint of chemical reaction - Fungicides containing mercury, for example, should not be used near selenium oxide rectifiers, as chemical reduction of the oxide to metallic selenium may occur.

Remedy — Use only non-nutrient substances - Coat the finished equipment with an appropriate fungicide - Repeat application of fungicide as part of regular maintenance procedure - Use encapsulation, or hermetic sealing.

SAND AND DUST

Effect on all items: Presence of sand and dust may cause deterioration as follows: (a) finely finished surfaces may be scratched and abraided. (b) Friction between sliding surfaces may be increased. (c) Lubricants may be contaminated. (d) Orifices may be clogged. (e) Resilient materials may be penetrated. (f) Hard materials may be worn, scratched, or chipped. (g) Sand is a silicate, exceedingly hard, and an excellent abrasive. (h) Dust consists essentially of exceedingly fine particles which may or may not be electrically conductive - Frequently they are soluble in water.

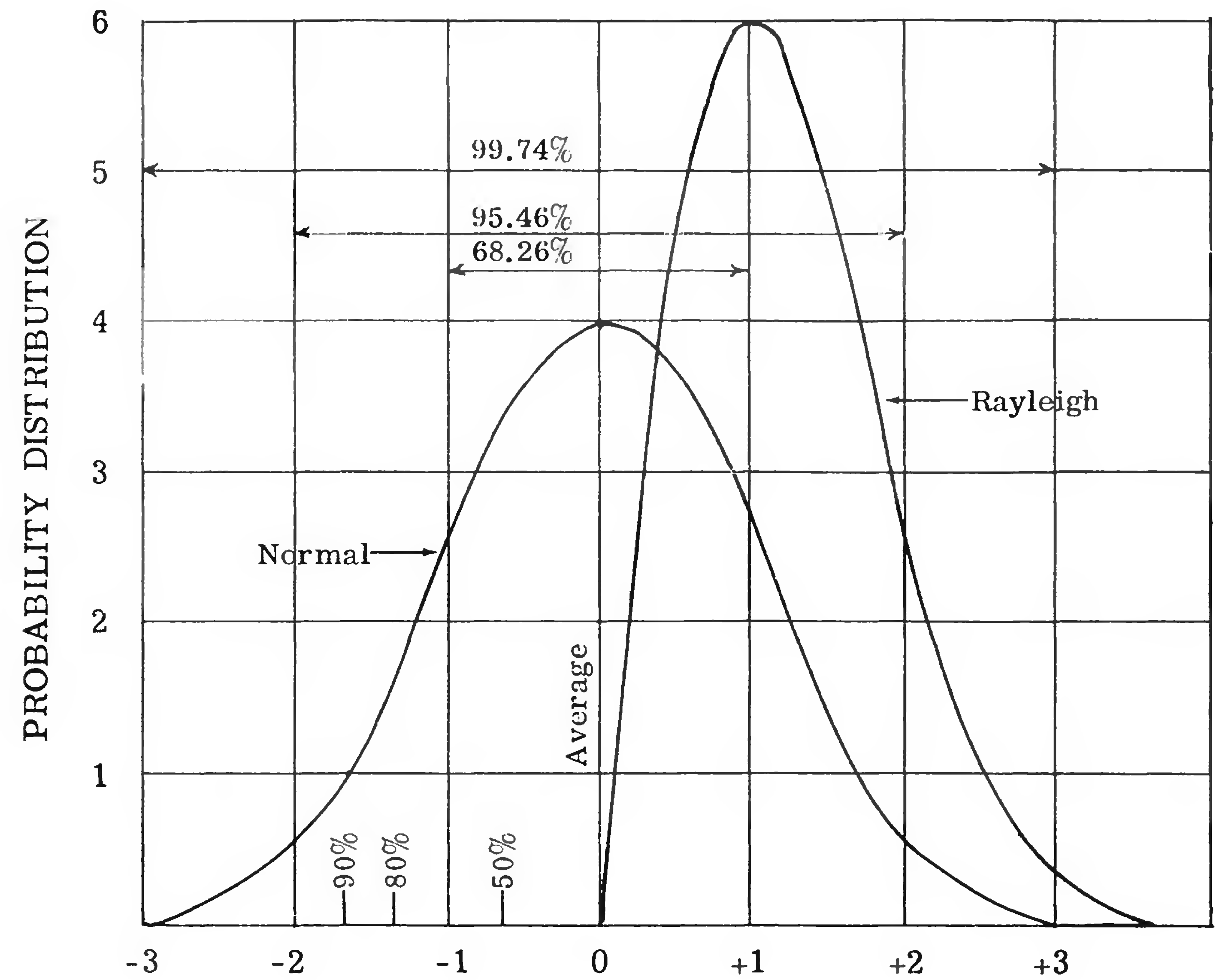
Remedy — Use sealed bearings - Use encapsulation, or hermetic sealing - Design dust shields around equipment - Provide for frequent maintenance and overhaul.

ELECTRO-MAGNETIC RADIATION

Effect on all items: Electro-magnetic radiation may affect items as follows: (a) radiation may be absorbed by ferrous substances and set up eddy currents which produce heat. (b) When produced within equipment, may be radiated or conducted through power lines. (c) When conducted into equipment over power-lines or through receiving equipment, may saturate the electronic circuits of the equipment.

Remedy — Use laminated, rather than solid construction - Use shielding - Use band-rejection filters in power lines - Use line filters - Use band-rejection filters.

FIGURE 3.13 NORMAL FREQUENCY CURVE AND RAYLEIGH DISTRIBUTION



$$\sigma = \sqrt{\frac{\Sigma X}{N}}$$

where X = deviation of individual values

N = number of data

Area under the Probability Curve for intercepts equal to:

1σ = 68.26%	50% = 0.675σ
2σ = 95.46%	80% = 1.282σ
3σ = 99.74%	90% = 1.645σ
4σ = 99.994%	
5σ = 99.999578%	[1 - P = 4.22×10^{-6}]
6σ = 99.99, 99, 99, 9145%	[1 - P = 8.55×10^{-10}]

FIGURE 3.14 NUMBER OF TESTS WITHOUT FAILURE VS RELIABILITY AND CONFIDENCE

	Confidence Level, Per Cent											
Reliability	50	60	70	75	80	85	90	95	97.5	99	99.5	99.9
.999999	693150	916290	1203970	1386290	1609440	1897120	2302590	2995730	3688889	4605170	5298320	6907760
.99999	69315	91629	120397	138629	160944	189712	230259	299573	368889	460517	529832	690776
.9999	6932	9163	12040	13863	16094	18971	23026	29957	36889	46052	52983	69078
.999	693	916	1204	1386	1609	1897	2303	2996	3689	4605	5298	6908
.998	347	458	602	694	805	949	1152	1498	1845	2303	2650	3454
.997	231	305	401	462	537	632	768	999	1230	1535	1766	2303
.996	173	229	301	346	401	473	575	747	920	1149	1322	1723
.995	138	183	241	277	321	379	460	598	737	920	1058	1379
.994	115	152	201	230	267	315	383	498	613	765	880	1148
.993	99	130	174	198	229	270	328	427	526	657	755	985
.992	86	114	150	173	200	236	287	373	460	574	660	860
.991	77	101	134	153	178	210	255	332	408	510	586	764
.99	69	92	120	138	160	188	229	298	367	459	527	688
.98	34	45	60	69	80	94	114	149	183	228	263	342
.97	23	30	40	45	53	62	76	99	121	151	174	227
.96	17	23	30	34	39	46	57	74	91	113	130	170
.95	14	18	24	27	31	37	45	58	72	90	103	135
.94	11	15	20	22	26	31	37	49	60	75	86	112
.93	10	13	17	19	22	26	32	42	51	64	74	96
.92	9	11	15	17	19	23	28	36	45	55	64	83
.91	8	10	13	15	17	20	25	32	39	49	57	74
.9	7	9	12	13	15	18	22	29	35	44	51	66
.8	3	4	6	6	7	9	11	14	17	21	24	31
.7	2	3	4	4	5	6	7	9	11	13	15	20
.6	2	2	3	3	4	4	5	6	8	9	11	14
.5	1	1	2	2	3	3	4	5	6	7	8	10

$$\text{Number of tests} = \frac{\ln(1 - \text{confidence level})}{\ln(1 - \text{reliability})}$$

(Expanded from tables in NOTS TECH. MEMO. NO.1113 by R. M. McClung)

FIGURE 3.15 PROBABILITY CURVES AS A FUNCTION OF NUMBER OF COMPONENTS

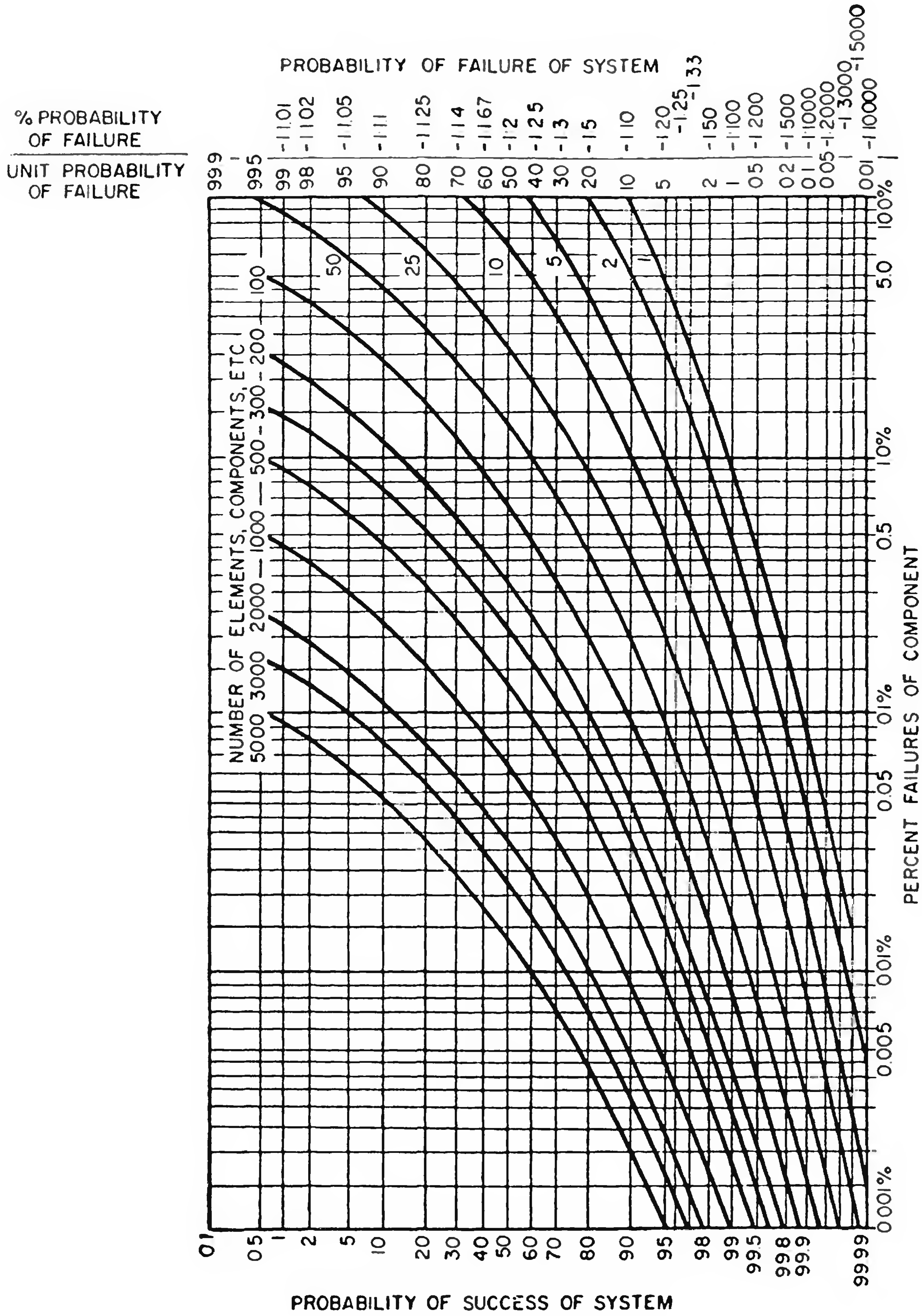


FIGURE 3.16 PROBABILITY OF SYSTEM SUCCESS AS A FUNCTION OF NUMBER OF FAILED COMPONENTS AND NUMBER OF TESTS (90% CONFIDENCE LEVEL)

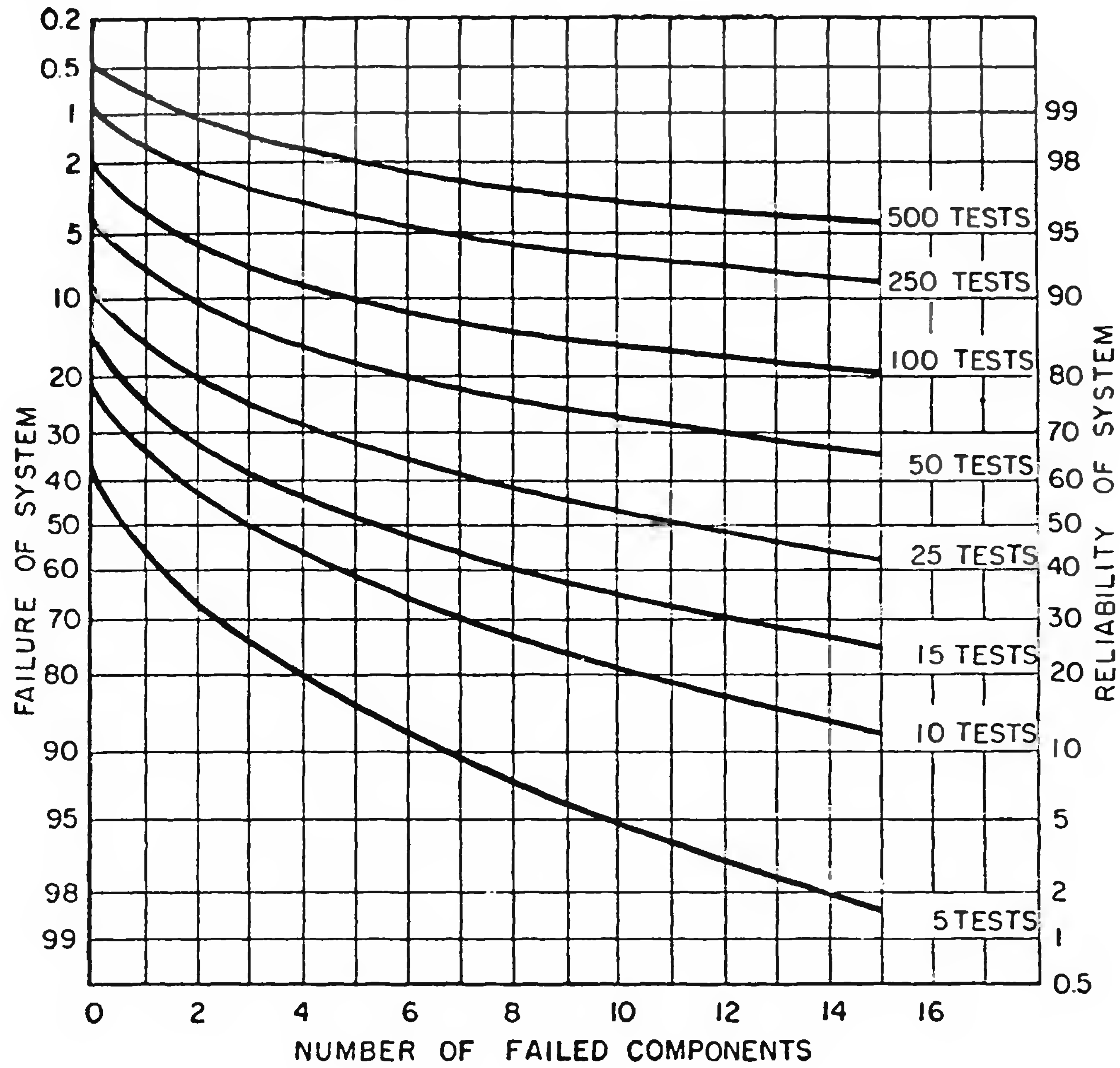


FIGURE 3.17 MISSILE RELIABILITY VS. FAILURES PER CYCLE OF OPERATION (FOR CYCLES FROM 1 TO 150)

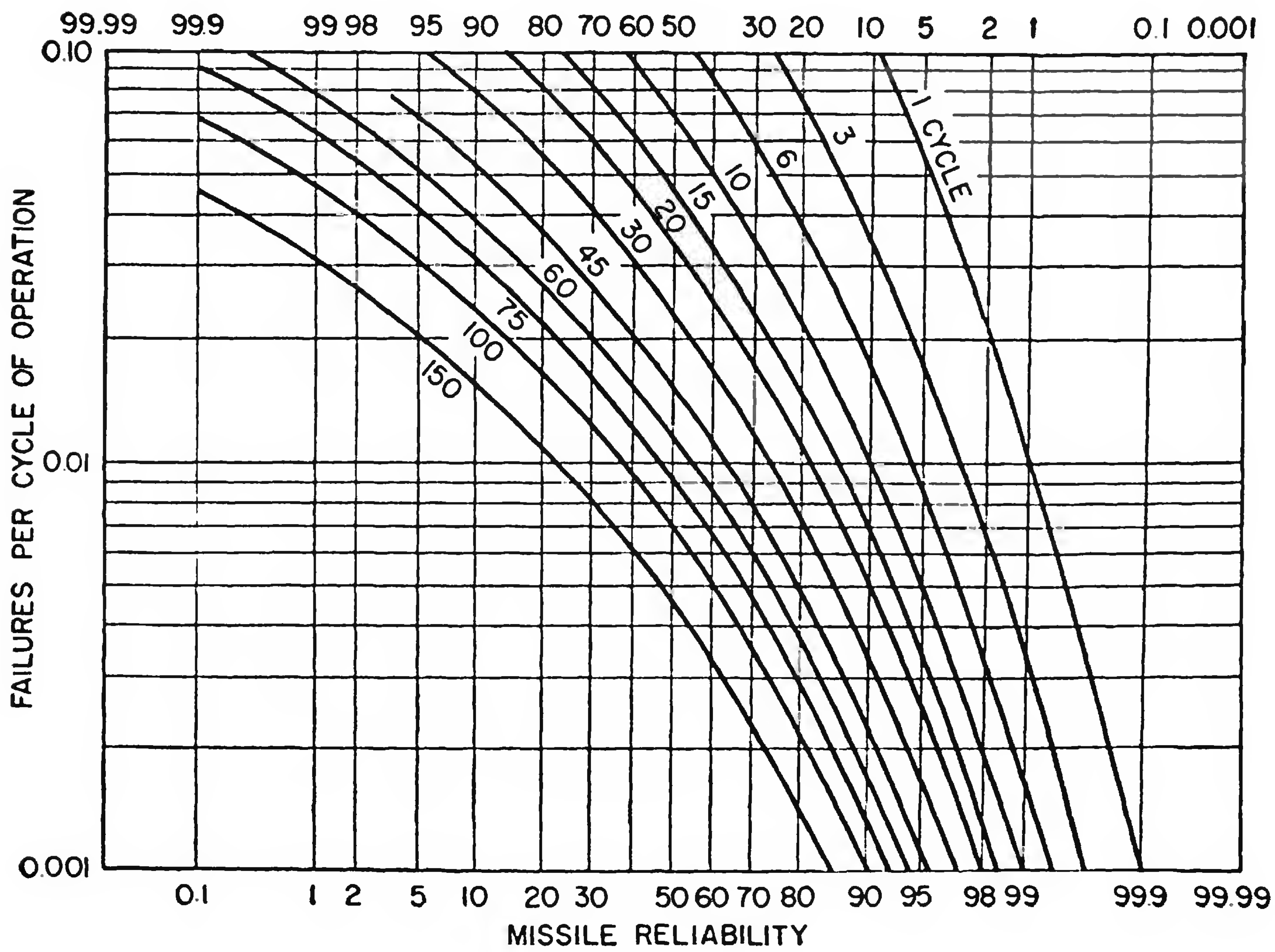


FIGURE 3.18 LIFE TEST SAMPLE SIZE

The sample size required in a Life Test to be sure (with probability P %) that fewer than k% of future units will fail in a time shorter than the shortest life in the sample.

k % \ P in %	99.9	99	95	75	50
0.1	6977	4652	3026	1401	701
1	689	459	299	139	70
2	343	229	149	69	35
3	227	152	99	46	23
4	170	113	74	34	17
5	135	90	59	28	14
10	66	44	29	14	7
15	43	29	19	9	5
20	31	21	14	7	4
25	25	17	11	5	3
30	20	13	9	4	2
35	16	11	7	4	2
40	14	10	6	3	2
45	12	8	6	3	2
50	10	7	5	2	1

FIGURE 3.19 MASTER TABLE FOR REDUCED INSPECTION (SINGLE SAMPLING ONLY)

(From PRODUCT ENGINEERING, March, 1953)

Sample Size Code Letter	Sample Size	Acceptable Quality Level, percent																					
		0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10.0	
		Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A, B, C, D	2	↓		↓		↓		↓		↓		↓		0	1	↓		↓					
E	2	↓		↓		↓		↓		↓		↓		0	1	↓		↓		1	2	1	2
F	3	↓		↓		↓		↓		↓		0	2	↑		↓		1	2	1	2	2	3
G	5	↓		↓		↓		↓		0	1	↑		↓		1	2	1	2	2	3	3	4
H	7	↓		↓		↓		0	1	↑		↓		1	2	1	2	2	3	3	4	3	4
I	10	↓		↓		0	1	↑		↓		1	2	1	2	2	3	2	3	3	4	4	5
J	15	↓		0	2	↑		↓		1	2	1	2	2	3	2	3	3	4	4	5	6	7
K	22	0	1	↑		↓		1	2	1	2	2	3	2	3	3	4	4	5	5	6	8	9
L	30	↑		↓		1	2	1	2	2	3	2	3	3	4	4	5	5	6	7	8	11	12
M	45	↓		1	2	1	2	2	3	2	3	3	4	4	5	5	6	7	8	10	11	13	14
N	60	1	2	1	2	2	3	2	3	3	4	4	6	5	6	6	7	9	10	12	13	15	16
O	90	1	2	2	3	2	3	3	4	4	5	5	6	6	7	9	10	11	12	14	15	18	19

↓ Use first sampling plan below arrow ↑ Use first sampling plan above arrow.

FIGURE 3.20 MASTER TABLE FOR NORMAL AND TIGHTENED INSPECTION (DOUBLE SAMPLING)

Sample Size Code Letter	Sample	Sample Size	Cumulative Sample Size	Acceptance Quality Levels for Tightened Inspection Use Column III In Figure 3.20(A) For Code Letter																					
				0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10.0			
				Acceptance Quality Levels for Normal Inspection Use Column II in Figure 3.20(A) For Code Letter																					
				0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5		4.0		6.5		10.0	
				Ac	Rc	Ac	Rc	Ac	Rc	Ac	Rc	Ac	Rc	Ac	Rc	Ac	Rc	Ac	Rc	Ac	Rc	Ac	Rc	Ac	Rc
D	1st	5	5	↓		↓		↓		↓		↓		↓		↓		*		*		↓		1	3
	2nd	10	15																					2	3
E	1st	7	7	↓		↓		↓		↓		↓		↓		*		↑		↓		0	3	1	5
	2nd	14	21																			2	3	4	5
F	1st	10	10	↓		↓		↓		↓		↓		*		↑		↓		0	3	1	4	2	6
	2nd	20	30																	2	3	3	4	5	6
G	1st	15	15	↓		↓		↓		↓		*		↑		↓		0	3	1	4	1	5	3	7
	2nd	30	45															2	3	3	4	4	5	6	7
H	1st	25	25	↓		↓		↓		*		↑		↓		1	3	1	4	2	5	3	7	5	11
	2nd	50	75													2	3	3	4	4	5	6	7	10	11
I	1st	35	35	↓		↓		*		↑		↓		0	3	1	3	1	5	2	7	3	12	6	15
	2nd	70	105											2	3	2	3	4	5	6	7	11	12	14	15
J	1st	50	50	↓		*		↑		↓		0	3	1	4	1	6	2	7	3	10	5	15	8	21
	2nd	100	150									2	3	3	4	5	6	6	7	9	10	14	15	20	21
K	1st	75	75	*		↑		↓		0	3	1	3	1	6	2	8	4	9	5	12	7	20	12	29
	2nd	150	225							2	3	2	3	5	6	7	8	8	9	11	12	19	20	28	29
L	1st	100	100	↑		↓		0	3	1	4	1	6	2	6	3	8	5	12	7	17	10	31	14	49
	2nd	200	300					2	3	3	4	5	6	5	6	7	8	11	12	16	17	30	31	48	49
M	1st	150	150	↓		0	3	1	3	2	5	2	7	3	8	5	14	7	19	11	29	15	47	21	65
	2nd	300	450			2	3	2	3	4	5	6	7	7	8	13	14	18	19	28	29	46	47	64	65
N	1st	200	200	0	3	1	3	1	6	2	7	3	8	4	10	6	17	9	25	12	36	18	67	27	89
	2nd	400	600	2	3	2	3	5	6	6	7	7	8	9	10	16	17	24	25	35	36	66	67	88	89
O	1st	300	300	1	3	1	6	2	7	3	9	4	11	6	17	8	26	12	36	18	55	26	88	38	123
	2nd	600	900	2	3	5	6	6	7	8	9	10	11	16	17	25	26	35	36	54	55	87	88	122	123

↓ Use first sampling below arrow ↑ Use first sampling plan above arrow * Use corresponding single sampling plan.

FIGURE 3.20(A) CODE LETTERS

Sample Lot Size	Inspection Levels I Reduced	II Normal	III Tightened	Sample Lot Size	Inspection Levels I Reduced	II Normal	III Tightened
2-8	A	A	C	301-500	G	I	K
9-15	A	B	D	501-800	H	J	L
16-25	B	C	E	801-1,300	I	K	L
26-40	B	D	F	1,301-3,200	J	L	M
41-65	C	E	G	3,201-8,000	L	M	N
66-110	D	F	H	8,001-22,000	M	N	O
111-180	E	G	I	22,001-110,000	N	O	P
181-300	F	H	J	110,001-550,000	O	P	Q
				550,001 and over	P	Q	Q

FIGURE 3.21 LIMITS OF PROCESS AVERAGE FOR ACCEPTABLE QUALITY LEVELS FROM 0.15 TO 10.0

Number of Sample Units Included in Estimated Process Average	UPPER LIMITS — Acceptable Quality Level, percent 0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10.0
750–899....	0.555	0.772	1.061	1.492	2.04	2.78	4.15	6.09	9.16	13.30
900–1,099..	0.518	0.724	1.000	1.415	1.95	2.66	4.00	5.90	8.92	13.00
1,100–1,299.	0.485	0.683	0.948	1.348	1.87	2.56	3.87	5.73	8.71	12.74
1,300–1,499.	0.461	0.651	0.907	1.296	1.80	2.48	3.77	5.60	8.54	12.54
1,500–1,699.	0.440	0.625	0.874	1.255	1.75	2.42	3.69	5.50	8.41	12.37
1,700–1,899.	0.424	0.604	0.847	1.220	1.71	2.37	3.59	5.41	8.30	12.24
1,900–2,249.	0.405	0.579	0.817	1.181	1.66	2.31	3.54	5.32	8.18	12.08
2,250–2,749.	0.383	0.550	0.779	1.134	1.50	2.23	3.45	5.20	8.03	11.90
2,750–3,499.	0.358	0.518	0.739	1.083	1.54	2.16	3.35	5.07	7.87	11.70
3,500–4,999..	0.328	0.480	0.691	1.021	1.46	2.06	3.23	4.92	7.67	11.46
5,000–6,999..	0.300	0.444	0.645	0.962	1.39	1.97	3.11	4.77	7.49	11.22
7,000–8,999..	0.280	0.418	0.612	0.920	1.34	1.91	3.03	4.67	7.36	11.06
9,000–10,999..	0.266	0.400	0.590	0.892	1.30	1.87	2.97	4.60	7.27	10.95
11,000–13,499.	0.254	0.384	0.570	0.866	1.27	1.83	2.92	4.54	7.18	10.85
13,500–17,499.	0.243	0.371	0.552	0.844	1.24	1.80	2.88	4.48	7.11	10.76
	LOWER LIMITS									
750–899....	No Reduced					0.22	0.85	1.91	3.84	6.70
900–1,099..					0.05	0.34	1.00	2.10	4.08	7.00
1,100–1,299.	Inspection For				0.13	0.44	1.13	2.27	4.29	7.26
1,300–1,499..				0.004	0.20	0.52	1.23	2.40	4.46	7.46
1,500–1,699..	Small Samples			0.045	0.25	0.58	1.31	2.50	4.59	7.63
1,700–1,899..				0.080	0.29	0.63	1.41	2.59	4.70	7.76
1,900–2,249.				0.119	0.34	0.69	1.46	2.68	4.82	7.92
2,250–2,749.	And Low A.Q.L.		0.021	0.166	0.40	0.77	1.55	2.80	4.97	8.10
2,750–3,499.			0.061	0.217	0.46	0.84	1.65	2.93	5.13	8.30
3,500–4,999.		0.020	0.109	0.279	0.54	0.94	1.77	3.08	5.33	8.54
5,000–6,999.		0.056	0.155	0.338	0.61	1.03	1.89	3.23	5.51	8.78
7,000–8,999.	0.020	0.082	0.188	0.380	0.66	1.09	1.97	3.33	5.64	8.94
9,000–10,999.	0.034	0.100	0.210	0.408	0.70	1.13	2.03	3.40	5.73	9.05
11,000–13,499.	0.046	0.116	0.230	0.434	0.73	1.17	2.08	3.46	5.82	9.15
13,500–17,499.	0.057	0.129	0.248	0.456	0.76	1.20	2.12	3.52	5.89	9.24

[From PRODUCT ENGINEERING, March, 1953]

FIGURE 3.22 CUMULATIVE PERCENTS CORRESPONDING TO VARIOUS SAMPLE SIZES

Ob. No.	Sample Size																				
	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	5	4.5	4.2	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.9	1.8	1.7	1.7
2	15	13.6	12.5	11.5	10.7	10.0	9.4	8.8	8.3	7.9	7.5	7.1	6.8	6.5	6.25	6.0	5.8	5.6	5.4	5.2	5.0
3	25	22.7	20.8	19.2	17.8	16.7	15.6	14.7	13.9	13.2	12.5	11.9	11.4	10.9	10.4	10.0	9.6	9.3	8.9	8.6	8.3
4	35	31.8	29.2	26.9	25.0	23.3	21.9	20.6	19.4	18.4	17.5	16.7	15.9	15.2	14.6	14.0	13.5	13.0	12.5	12.1	11.7
5	45	40.9	37.5	34.6	32.1	30.0	28.1	26.4	25.0	23.7	22.5	21.4	20.4	19.6	18.75	18.0	17.3	16.7	16.1	15.5	15.0
6	55	50.0	45.8	42.3	39.2	36.7	34.4	32.3	30.6	29.0	27.5	26.2	25.0	23.9	22.9	22.0	21.2	20.4	19.6	19.0	18.3
7	65	59.1	54.2	50.0	46.4	43.3	40.6	38.2	36.1	34.2	32.5	30.9	29.6	28.3	27.1	26.0	25.0	24.0	23.2	22.4	21.7
8	75	68.2	62.5	57.7	53.5	50.5	46.9	44.1	39.5	37.5	34.1	32.6	34.1	32.6	31.25	30.0	28.9	27.8	26.8	25.9	25.0
9	85	77.3	70.8	65.4	60.7	56.7	53.1	50.0	47.2	44.8	42.5	40.5	38.7	37.0	35.4	34.0	32.7	31.5	30.4	29.3	28.3
10	95	86.4	79.2	73.1	67.8	63.3	59.4	55.9	52.8	50.0	47.5	45.2	43.2	41.3	39.6	38.0	36.6	35.2	33.9	32.8	31.7
11		95.5	87.5	80.8	75.0	70.0	65.6	61.8	58.4	55.3	52.5	50.0	47.7	45.7	43.75	42.0	40.4	38.9	37.5	36.2	35.0
12			95.8	88.5	82.1	76.7	71.9	67.7	63.9	60.6	57.5	54.7	52.2	50.0	47.9	46.0	44.2	42.6	41.1	39.7	38.3
13				96.2	89.2	83.3	78.1	73.6	69.4	65.8	62.5	59.5	56.8	54.4	52.1	50.0	48.1	46.3	44.6	43.1	41.7
14					96.4	90.0	84.4	79.5	75.0	71.1	67.5	64.4	61.4	58.7	56.25	54.0	51.9	50.0	48.2	46.6	45.0
15						96.7	90.6	85.4	80.6	76.4	72.5	69.1	66.0	63.1	60.4	58.0	55.8	53.7	51.8	50.0	48.3
16							96.9	91.2	86.1	81.6	77.5	73.8	70.5	67.4	64.6	62.0	59.6	57.4	55.4	53.5	51.7
17								97.1	91.7	86.9	82.5	78.6	75.0	71.8	68.75	66.0	63.5	61.1	58.9	56.9	55.0
18									97.2	92.2	87.5	83.4	79.6	76.1	72.9	70.0	67.3	64.8	62.5	60.4	58.3
19										97.4	92.5	88.1	84.1	80.5	77.1	74.0	71.2	68.5	66.1	63.8	61.7
20											97.5	93.0	88.6	84.8	81.25	78.0	75.0	72.2	69.6	67.3	65.0
21												97.7	93.2	89.2	85.4	82.0	78.8	75.9	73.2	70.7	68.3
22													97.7	93.5	89.6	86.0	82.7	79.6	76.8	74.2	71.7
23														97.9	93.75	90.0	86.5	83.3	80.4	77.6	75.0
24															97.9	94.0	90.4	87.0	83.9	81.1	78.3
25																98.0	94.2	90.7	87.5	84.5	81.7
26																	98.1	94.4	91.1	88.0	85.0
27																		98.1	94.6	91.4	88.3
28																			98.2	94.9	91.7
29																				98.3	95.0
30																					98.3

Ob. No. = Observation Number.

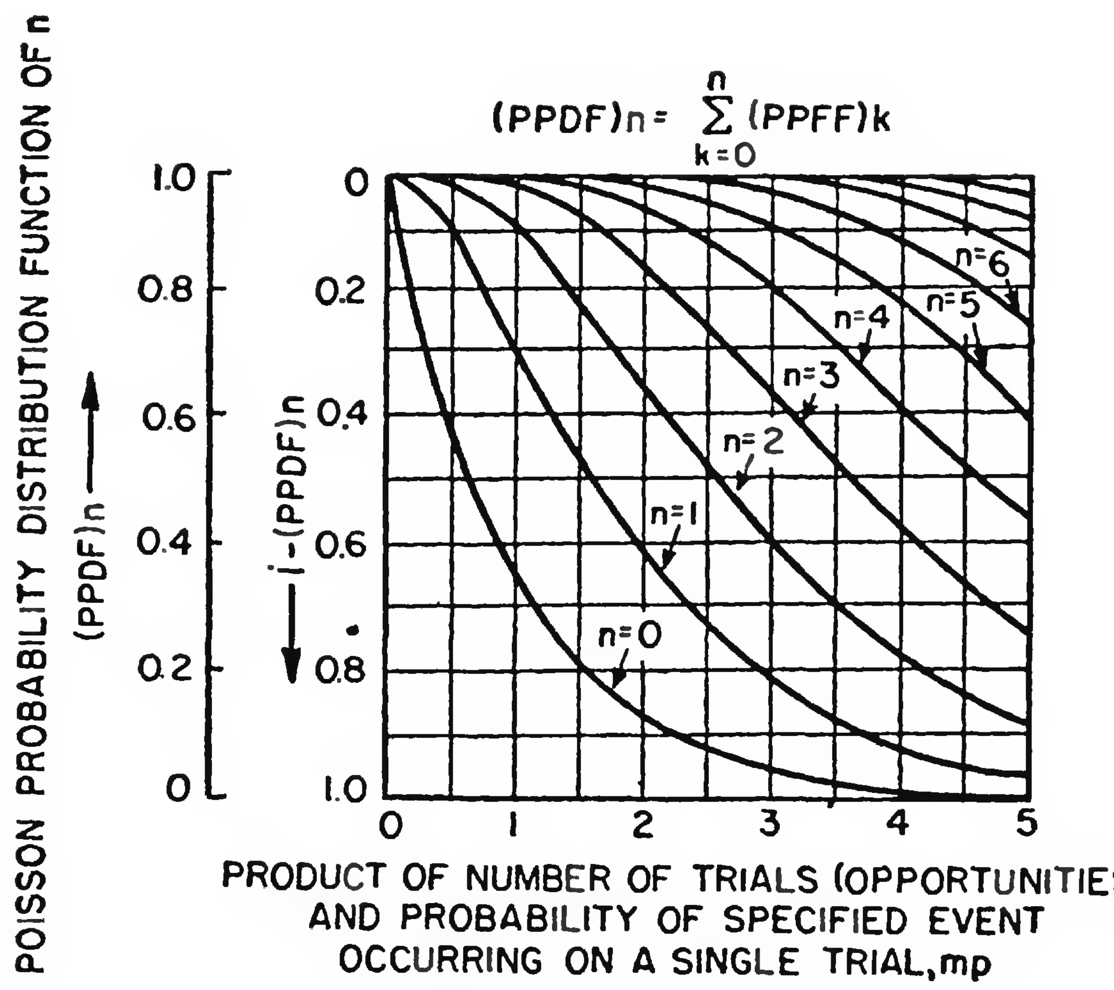
FIGURE 3.23 & 3.24 THE POISSON PROBABILITY DISTRIBUTION FUNCTION OF n, (PPFF)n

$$(\text{PPFF})n = \frac{e^{-mp}(mp)^n}{n!}$$

m = number of trials or opportunities
p = probability of event occurring on a single trial
n = number of successes

n	mp						
	0.2	0.5	1.0	2.0	3.0	4.0	5.0
0	0.81873	0.60653	0.36788	0.13535	0.049787	0.018322	0.007638
1	.16375	.30304	.36788	.27067	.14936	.07329	.03369
2	.016375	.075826	.18394	.27067	.22406	.14652	.084225
3	.0010916	.012636	.061314	.18045	.22406	.19537	.14042
4	.000054582	.0015762	.01533	.090224	.16803	.19537	.17547
5		.00015762	.0030657	.036090	.10082	.15629	.17547
6			.00049021	.012030	.050410	.10420	.14622
7				.0034371	.021604	.05954	.10445
8				.00085933	.0081015	.029770	.065279
9				.00019095	.0027001	.013230	.036266
10					.00081016	.0052925	.018133
11					.00022095	.0019245	.0082421
12						.0006415	.0034342
						.00019739	.0013209
							.00047176

(PPFF)n expresses the probability of some event occurring exactly n times, when m is the number of trials or opportunities, and p is the probability of the event occurring on a single trial.



[Figure 3.23]

FIGURE 3.23 STATISTICS OF THE MORE COMMON DISTRIBUTION LAWS

	Symbol	Normal Law	Poisson Law	Binomial L
Algebraic Definition		$\frac{1}{\sqrt{2\pi}\,\sigma} e^{-(n-\alpha)^2/2\sigma^2}$	$\frac{\epsilon^n e^{-\epsilon}}{n!}$	$C_n^m p^n (1 - p$
1st Expectation of n	$\epsilon_1(n)$	α	ϵ	mp
2nd Expectation of δ	ϵ_2	σ^2	ϵ	$mp(1-p)$
3rd Expectation of δ	ϵ_3	0	ϵ	$mp(1-p)(1-$
4th Expectation of δ	ϵ_4	3σ	$\epsilon + 3\epsilon^2$	$mp(1-p) + 3m(m-1)(1-p)^2 p^2$
Standard Deviation	σ	σ	$\sqrt{\epsilon}$	$\sqrt{mp(1-}$
Asymmetry (Skewness)	$\sqrt{\beta_1}$	0	$\frac{1}{\sqrt{\epsilon}}$	$\frac{1-2p}{\sqrt{mp(1-}}$
Flatness (Kurtosis)	β_2	3	$3 + \frac{1}{\epsilon}$	$3\,\frac{m-2}{m} + \frac{}{mp(1-p)}$
$3\beta_1 - 2\beta_2 + 6$	J	0	> 0	> 0
Equations for Determining Constants		$\alpha = \bar{n}$ $\sigma = \sigma$	$\epsilon = \bar{n}$	$p = 1 -$ $m = \frac{\bar{n}}{p}$

	Pearson Type I	Pearson Type II	Pearson Type III
Algebraic Definition	$\frac{(m_1+m_2-1)!}{(m_1-1)!\,(m_2-1)!} \frac{(n-\alpha_1)^{m_1-1}(\alpha_2-n)^{m_2-1}}{(\alpha_2-\alpha_1)^{m_1+m_2-1}}$	$\frac{(2m-1)!}{[(m-1)!]^2} \frac{[(n-\alpha_1)(\alpha_2-n)]^{m-1}}{(\alpha_2-\alpha_1)^{2m-1}}$	$\frac{\gamma^m (n-\alpha)^{m-1} e^{-\gamma(n-\alpha)}}{(m-1)!}$
1st Expectation of n	$\frac{m_2\alpha_1 + m_1\alpha_2}{m_1+m_2}$	$\frac{\alpha_2+\alpha_1}{2}$	$\alpha + \frac{m}{\gamma}$
2nd Expectation of δ	$\frac{m_1 m_2}{(m_1+m_2+1)}\left(\frac{\alpha_2-\alpha_1}{m_1+m_2}\right)^2$	$\frac{(\alpha_2-\alpha_1)^2}{4(2m+1)}$	$\frac{m}{\gamma^2}$
3rd Expectation of δ	$\frac{2m_1 m_2(m_2-m_1)}{(m_1+m_2+2)(m_1+m_2+1)}\left(\frac{\alpha_2-\alpha_1}{m_1+m_2}\right)^3$	0	$\frac{2m}{\gamma^3}$
4th Expectation of δ	$\frac{3m_1^2 m_2^2(m_1+m_2) + 6m_1 m_2(m_1^2 - m_1 m_2 + m_2^2)}{(m_1+m_2+3)(m_1+m_2+2)(m_1+m_2+1)}\left(\frac{\alpha_2-\alpha_1}{m_1+m_2}\right)^4$	$\frac{3(\alpha_2-\alpha_1)^4}{16(2m+3)(2m+1)}$	$3\,\frac{m(m+2)}{\gamma^4}$
Standard Deviation	$\sqrt{\frac{m_1 m_2}{m_1+m_2+1}}\left(\frac{\alpha_2-\alpha_1}{m_1+m_2}\right)$	$\frac{\alpha_2-\alpha_1}{2\sqrt{2m+1}}$	$\frac{\sqrt{m}}{\gamma}$
Asymmetry (Skewness)	$\sqrt{\frac{m_1+m_2+1}{m_1 m_2}}\,\frac{2(m_2-m_1)}{m_1+m_2+2}$	0	$\frac{2}{\sqrt{m}}$
Flatness (Kurtosis)	$3 + 6\,\frac{(m_1+m_2)(m_1^2 - 3m_1 m_2 + m_2^2 + m_1 + m_2) - 6m_1 m_2}{m_1 m_2(m_1+m_2+3)(m_1+m_2+2)}$	$3 - \frac{6}{2m+3}$	$3 + \frac{6}{m}$
$3\beta_1 - 2\beta_2 + 6$	> 0	> 0	0
Equations for Determining Constants	See Philosophical Transactions, Vol. 186, *A*, pp. 367–371.	$2m = 3\left(\frac{5-\beta_2}{\beta_2-3}\right)$ $\alpha_1 = \bar{n} - \sqrt{2m+1}\,\sigma$ $\alpha_2 = \bar{n} + \sqrt{2m+1}\,\sigma$	$m = \frac{4}{\beta_1}$ $\gamma = \frac{2}{\sigma\sqrt{\beta_1}}$ $\alpha = \bar{n} - \frac{2\sigma}{\sqrt{\beta_1}}$

	Pearson Type IV	Gram–Charlier
Algebraic Definition	$\frac{\gamma[\gamma^2+2^2][\gamma^2+4^2]\ldots[\gamma^2+(2m)^2]\beta^{2m+1}}{2(2m)!\sinh\frac{\gamma\pi}{2}} \frac{e^{-\gamma\tan^{-1}\frac{n-\alpha}{\beta}}}{[(n-\alpha)^2+\beta^2]^{m+1}}$	$\frac{1}{\sigma}\left[\phi_0\left(\frac{n-\alpha}{\sigma}\right) + A_1\phi_1\left(\frac{n-\alpha}{\sigma}\right) + \ldots + A_4\phi_4\left(\frac{n-\alpha}{\sigma}\right)\right]$
1st Expectation of n	$\alpha - \frac{\beta\gamma}{2m-1}$	$\alpha - \sigma A_1$
2nd Expectation of δ	$\frac{\beta^2\gamma^2}{(2m-2)(2m-1)^2} + \frac{\beta^2}{2m-2}$	$\sigma^2(1 + 2A_2 - A_1^2)$
3rd Expectation of δ	$-\frac{4\beta^3\gamma^3}{(2m-3)(2m-2)(2m-1)^3} - \frac{4\beta^3\gamma}{(2m-3)(2m-2)(2m-1)}$	$\sigma^3(-6A_3 + 6A_1A_2 - 2A_1^3)$
4th Expectation of δ	$\frac{3\beta^4\gamma^4(2m+5)}{(2m-4)(2m-3)(2m-2)(2m-1)^4} + \frac{6\beta^4\gamma^2(2m+1)}{(2m-4)(2m-3)(2m-2)(2m-1)^2} + \frac{3\beta^4}{(2m-4)(2m-2)}$	$\sigma^4(3 - 6A_1^2 + 12A_2 + 24A_4 - 24A_1A_3 + 12A_1^2A_2 - 3A_1^4)$
Standard Deviation	$\frac{\beta}{2m-1}\sqrt{\frac{\gamma^2+(2m-1)^2}{2m-2}}$	$\sigma\sqrt{1 + 2A_2 - A_1^2}$
Asymmetry (Skewness)	$\frac{-4\gamma}{2m-3}\sqrt{\frac{2m-2}{\gamma^2+(2m-1)^2}}$	$\frac{-6A_3 + 6A_1A_2 - 2A_1^3}{(1 + 2A_2 - A_1^2)^{3/2}}$
Flatness (Kurtosis)	$3\,\frac{(2m+5)(2m-2)}{(2m-3)(2m-4)} - \frac{24}{\gamma^2+(2m-1)^2}\,\frac{(2m-2)(2m-1)^2}{(2m-3)(2m-4)}$	$3 + 6\,\frac{4A_4 - 4A_1A_3 - 2A_2^2 + 4A_1^2A_2 - A_1^4}{(1 + 2A_2 - A_1^2)^2}$
$3\beta_1 - 2\beta_2 + 6$	< 0	. . .
Equations for Determining Constants	$4m^2(\beta_2 + \frac{3}{2}\beta_1 - 3) - 2m(7\beta_2 - 9\beta_1 - 15) + (12\beta_2 - \frac{27}{2}\beta_1 - 18) = 0$ $\gamma^2 = \frac{(2m-1)^2(2m-3)^2\beta_1}{16(2m-2) - (2m-3)^2\beta_1}$ $\beta = -\frac{(2m-1)(2m-3)\sqrt{\beta_1}\,\sigma}{4\gamma}$ $\alpha = \bar{n} - \frac{(2m-3)\sqrt{\beta_1}\,\sigma}{4}$	$A_1 = 0$* $\quad \sigma = \sigma$ $A_2 = 0$* $\quad 6A_3 = -\sqrt{\beta_1}$ $\alpha = \bar{n}$ $\quad 24A_4 = \beta_2 - 3$ * Of the six constants, σ, α, A_1, A_2, A_3, A_4 any two may be arbitrarily chosen. The choice $A_1 = A_2 = 0$ leads to the simplest equations, and is usually adopted.

FIGURE 3.25 THE POISSON PROBABILITY DISTRIBUTION FUNCTION OF n, (PPDF)n

$$(\mathrm{PPDF})n = \sum_{k=0}^{n} (\mathrm{PPFF})k = \frac{\sum_{k=0}^{n} e^{-mp}(mp)^k}{k!}$$

m = number of trials
p = probability of the event occurring on a single trial
n = number of successes

n	mp						
	0.2	0.5	1.0	2.0	3.0	4.0	5.0
0	0.81973	0.60653	0.36788	0.13535	0.04979	0.01832	0.00674
1	.98248	.90957	.73576	.40602	.19915	.09161	.04043
2	.99886	.98540	.91970	.67669	.42321	.23813	.12466
3	.99995	.99804	.98101	.85714	.64727	.43350	.26508
4		.99962	.99634	.94736	.81530	.62887	.44055
5		.99978	.99941	.98345	.91612	.78516	.61602
6			.99990	.99548	.96653	.88936	.76224
7				.99892	.98813	.94890	.86669
8				.99978	.99623	.97867	.93197
9				.99997	.99893	.99190	.96824
10					.99974	.99719	.98637
11					.99996	.99911	.99461
12						.99975	.99804
13						.99995	.99936
14							.99983

(PPDF)n expresses, as a function of mp, the probability that the number of events occurring will lie in the range from zero to the given value of n, inclusive.

FIGURE 3.26 ONE MINUS THE POISSON PROBABILITY DISTRIBUTION FUNCTION OF n

[1 — (PPDF)n]

m = number of trials
p = probability of the event occurring on a single trial
n = number of successes

n	mp						
	0.2	0.5	1.0	2.0	3.0	4.0	5.0
0	0.18127	0.39347	0.63212	0.86465	0.95021	0.98168	0.99326
1	0.1752	.09043	.26424	.59398	.80085	.90839	.95957
2	.00114	.01460	.08030	.32331	.57679	.76187	.87534
3	.00005	.00196	.01899	.14286	.35273	.56650	.73492
4		.00038	.00366	.05264	.18470	.37113	.55945
5		.00022	.00059	.01655	.08388	.21484	.38398
6			.00010	.00452	.03347	.11064	.23776
7				.00108	.01187	.05110	.13331
8				.00022	.00377	.02133	.06803
9				.00003	.00107	.00810	.03176
10					.00026	.00281	.01363
11					.00004	.00089	.00539
12						.00025	.00196
13						.00005	.00064
14							.00017

[1 — (PPDF)n] expresses, as a function of mp, the probability that the number of events occurring will be greater than the given value of n.

FIGURE 3.25 THE POISSON PROBABILITY DISTRIBUTION FUNCTION OF n, (PPDF)n

$$(PPDF)n = \sum_{k=0}^{n} (PPFF)k = \frac{\sum_{k=0}^{n} e^{-mp} (mp)^k}{k!}$$

m = number of trials
p = probability of the event occurring on a single trial
n = number of successes

n	mp 0.2	0.5	1.0	2.0	3.0	4.0	5.0
0	0.81973	0.60653	0.36788	0.13535	0.04979	0.01832	0.00674
1	.98248	.90957	.73576	.40602	.19915	.09161	.04043
2	.99886	.98540	.91970	.67669	.42321	.23813	.12466
3	.99995	.99804	.98101	.85714	.64727	.43350	.26508
4		.99962	.99634	.94736	.81530	.62887	.44055
5		.99978	.99941	.98345	.91612	.78516	.61602
6			.99990	.99548	.96653	.88936	.76224
7				.99892	.98813	.94890	.86669
8				.99978	.99623	.97867	.93197
9				.99997	.99893	.99190	.96824
10					.99974	.99719	.98637
11					.99996	.99911	.99461
12						.99975	.99804
13						.99995	.99936
14							.99983

(PPDF)n expresses, as a function of mp, the probability that the number of events occurring will lie in the range from zero to the given value of n, inclusive.

FIGURE 3.26 ONE MINUS THE POISSON PROBABILITY DISTRIBUTION FUNCTION OF n

[1 − (PPDF)n]

m = number of trials
p = probability of the event occurring on a single trial
n = number of successes

n	mp 0.2	0.5	1.0	2.0	3.0	4.0	5.0
0	0.18127	0.39347	0.63212	0.86465	0.95021	0.98168	0.99326
1	0.1752	.09043	.26424	.59398	.80085	.90839	.95957
2	.00114	.01460	.08030	.32331	.57679	.76187	.87534
3	.00005	.00196	.01899	.14286	.35273	.56650	.73492
4		.00038	.00366	.05264	.18470	.37113	.55945
5		.00022	.00059	.01655	.08388	.21484	.38398
6			.00010	.00452	.03347	.11064	.23776
7				.00108	.01187	.05110	.13331
8				.00022	.00377	.02133	.06803
9				.00003	.00107	.00810	.03176
10					.00026	.00281	.01363
11					.00004	.00089	.00539
12						.00025	.00196
13						.00005	.00064
14							.00017

[1 − (PPDF)n] expresses, as a function of mp, the probability that the number of events occurring will be greater than the given value of n.

SECTION 4—PROPERTIES OF MATERIALS STRUCTURES

PRINCIPAL NOTATIONS

a	angular deflection per unit length, or unit angular deflection
A	area
b	breadth, width or any or all linear dimensions
c	distance from neutral axis to extreme fiber
C	coefficient of moment in beam formula, or any constant
c', c"	constants
d	inner or smaller dia
D	outer or larger dia
e	eccentricity or moment arm
E	modulus of elasticity
F	force or system of forces
G	modulus of elasticity in shear (torsion)
h	height
I	moment of inertia
J	polar moment of inertia
k	radius of gyration
K	stress concentration factor, or coefficient of deflection in beam formula, or any constant
k', k"	constants
l	constant proportion of total length or span
L	total length or span
M	moment
M'	equivalent moment due to axial force and bending
n	ratio of new design to old design
FS	factor of safety based on ultimate strength
FS_y	factor of safety based on yield point
p	normal load per unit area, pressure
Q	flexural center
q	any number
r	inner or smaller radius
R	outer or larger radius, radius of curvature of a beam

PRINCIPAL NOTATIONS (cont.)

s = stress

s_m = stress at resonance

t = thickness

T = torque

V = shear force on a beam

V' = volume

w = uniformly distributed load or weight per unit length

W = total weight

y = elongation or deflection per unit length or per unit span, unit deflection

Z = section modulus

ρ = density or weight per unit volume

ϵ = total elongation or deflection

θ = total angular deflection

m = mass, slug ft^2 $= \frac{W}{g}$

f = natural frequency, cycles/sec

ω = natural frequency, rad/sec

f_d = damped natural frequency, cycles/sec

ω_d = damped natural frequency, rad/sec

ζ = damping factor,

c_c = critical damping coefficient

A, B, s_1, s_2 = arbitrary constants

δ = logarithmic decrement

γ = damping factor, structural or solid $= \frac{c}{c_c}$

ϕ = phase angle of lag between motion and impressed force

X_o = zero frequency deflection

X = amplitude

$\frac{X}{X_o}$ = magnification factor

F_{tr} = force transmitted thru flexible support

F_o = force transmitted directly with rigid mounting

x_F = displacement of force

e_F = velocity of force

D' = damping capacity, in. lb/cu in./cycle

FIGURE 4.1 SPECIFIC GRAVITIES AND WEIGHTS

Substance			Specific Gravity	Weight, Lb/cu ft.
METAL OR COMPOSITION				
Aluminum			1.70	168.5
Antimony			6.52	413.0
Barium			3.78	235.9
Beryllium			1.85	115.5
Bismuth			9.63	610.3
Boron			2.53	158.2
Brass:	80C.,	20Z	8.6	536.6
	70C.,	30Z	8.44	526.7
	60C.,	40Z	8.35	521.7
	50C.,	50Z	8.19	511.7
Bronze:	90C.,	10T	8.77	547.9
Cadmium			8.64	539.6
Calcium			1.54	96.1
Chromium			6.92	432.4
Cobalt			8.70	543.5
Copper			8.89	554.7
Gold			19.28	1204.3
Iridium			22.4	1399.0
Iron, cast			7.02 - 7.73	438.7 -- 482.4
Iron, wrought			7.8 - 7.9	486.7 -- 493.0
Lead			11.32	707.7
Magnesium			1.74	108.6
Manganese			7.30	455.5
Mercury (68° F)			13.54	845.3
Molybdenum			10.20	636.5
Nickel			8.80	549.1
Platinum			21.33	1333.5
Potassium			0.87	54.3
Silver			10.40 - 10.52	650.2 -- 657.1
Sodium			0.97	60.6
Steel, Carbon			7.83 - 7.86	489.0 -- 490.8
Tantalum			16.60	1035.8
Tellurium			6.25	390.0
Tin			7.29	454.9
Titanium			4.49	280.1
Tungsten			18.60 - 19.10	1161 -- 1192
Uranium			18.69	1166.9
Vanadium			6.32	394.4
Zinc			7.04 - 7.15	439.3 -- 446.8

FIGURE 4.1 SPECIFIC GRAVITIES AND WEIGHTS (cont.)

Substance	Specific Gravity	Weight Lb/cu ft.
VARIOUS SOLIDS		
Cork	—	14 -- 16
Carbon, Graphite	—	140
Rubber, Hard	—	74
Commercial	—	69
Gum	—	57 -- 58
Glass, flint	—	180 -- 370
Glass, common	2.40 - 2.60	156
Glass, plate or crown	2.45 - 2.72	161
Glass, crystal	2.90 - 3.00	184
Leather	0.86 - 1.02	59
Paper	0.70 - 1.15	58
Rubber, caoutchouc	0.92 - 0,96	59
Rubber goods	1.0 - 2.0	94
Sulphur	1.93 - 2.07	125
TIMBER, U. S. SEASONED		
Balsa	0.11 - 0.14	7 - 9
Ash, white-red	0.62 - 0.65	40
Cedar, white-red	0.32 - 0.38	22
Chestnut	0.66	41
Cypress	0.48	30
Fir, Douglas spruce	0.51	32
Fir, eastern	0.40	25
Elm	0.72	45
Hemlock	0.42 - 0.52	29
Hickory	0.74 - 0.84	49
Locust	0.73	46
Maple, hard	0.68	43
Maple, white	0.53	33
Oak, chestnut	0.86	54
Oak, live	0.95	59
Oak, red, black	0.65	41
Oak, white	0.74	46
Pine, Oregon	0.51	32
Pine, red	0.48	30
Pine, white	0.41	26
Pine, yellow, long-leaf	0.70	44
Pine, yellow, short-leaf	0.61	38
Poplar	0.48	30

FIGURE 4.1 SPECIFIC GRAVITIES AND WEIGHTS (cont.)

Substance	Specific Gravity	Weight Lb/cu ft.
TIMBER, U. S. SEASONED (Continued)		
Redwood, California	0.42	26
Spruce, white, black	0.40 - 0.46	27
Walnut, black	0.61	38
Walnut, white	0.41	26
[Moisture Contents: Seasoned timber 15 to 20% Green timber up to 50%]		
CERAMICS		
Elec. Porcelain	2.5	156
Hi Alumina	3.8	237
Sintered Alumina	4.0	249
Cemented Carbide	13.5	842
Thorium Oxide	10	624
VARIOUS LIQUIDS		
Alcohol, 100%	0.79	49
Acids, nitric 91%	1.50	94
Acids, sulphuric 87%	1.80	112
Oils, mineral, lubricants	0.90 - 0.93	57
Water, 4°C, max. density	1.0	62.428
Water, 100° C	0.9584	59.830
Water, ice	0.88 - 0.92	56
Water, snow, fresh fallen	0.125	8
Water, sea water	1.02 - 1.03	64
Liquid Oxygen 184° F		71.4
Liquid Nitrogen 195° F	Refer to water density at proper temperature	50.5
Acetone 20°C		49.4
Alcohol (methyl) 0°C		50.5
Benzene 0° C		56.1
Carbon Tetrachloride 20° C		99.6
Gasoline		41.0 - 43.0
Glycerin 0° C		78.6
Kerosene		51.2
Mercury		849.0
Turpentine		54.3
Water 0° C		62.422
Water (SP. GR. = 1.0000) 4° C		62.43
Water 20° C		62.319

FIGURE 4.1 SPECIFIC GRAVITIES AND WEIGHTS (cont.)

Substance	Specific Gravity	Weight Lb/cu ft.
GASES,		
Air, 0°C, 760 mm	1.0	0.08071
Ammonia	0.5920	0.0478
Carbon dioxide	1.5291	0.1234
Carbon monoxide	0.9673	0.0781
Gas, illuminating	0.35 - 0.45	0.028 - 0.036
Gas, natural	0.47 - 0.48	0.038 - 0.039
Hydrogen	0.0693	0.00559
Nitrogen	0.9714	0.0784
Oxygen	1.1056	0.0892
ASHLAR MASONRY		
Granite, syenite, gneiss	2.3 - 3.0	165
Limestone, marble	2.3 - 2.8	160
Sandstone, bluestone	2.1 - 2.4	140
MORTAR RUBBLE MASONRY		
Granite, syenite, gneiss	2.2 - 2.8	155
Limestone marble	2.2 - 2.6	150
Sandstone, bluestone	2.0 - 2.2	130
DRY RUBBLE MASONRY		
Granite, syenite, gneiss	1.9 - 2.3	130
Limestone, marble	1.9 - 2.1	125
Sandstone, bluestone	1.8 - 1.9	110
BRICK MASONRY		
Pressed brick	2.2 - 2.3	140
Common brick	1.8 - 2.0	120
Soft brick	1.5 - 1.7	100
CONCRETE MASONRY		
Cement, stone, sand	2.2 - 2.4	144
Cement, slag, etc	1.9 - 2.3	130
Cement, cinder, etc	1.5 - 1.7	100
VARIOUS BUILDING MATERIAL		
Ashes, cinders	—	40 - 45
Cement, portland, loose	—	90
Cement, portland, set	2.7 - 3.2	183
Lime, gypsum, loose	—	53 - 64
Mortar, set	1.4 - 1.9	103

FIGURE 4.1 SPECIFIC GRAVITIES AND WEIGHTS (cont.)

Substance	Specific Gravity	Weight Lb/cu ft.
Slags, bank slag	—	67 - 72
Slags, bank screenings	—	98 - 117
Slags, machine slag	—	96
Slags, slag sand	—	49 - 55
EARTH, ETC., EXCAVATED		
Clay, dry	—	63
Clay, damp, plastic	—	110
Clay and gravel, dry	—	100
Earth, dry, loose	—	76
Earth, dry, packed	—	95
Earth, moist, loose	—	78
Earth, moist, packed	—	96
Earth, mud, flowing	—	108
Earth, mud, packed	—	115
Riprap, limestone	—	80 - 85
Riprap, sandstone	—	90
Riprap, shale	—	105
Sand, gravel, dry, loose	—	90 - 105
Sand, gravel, dry, packed	—	100 - 120
Sand, gravel, dry, wet	—	118 - 120
EXCAVATION IN WATER		
Sand or gravel	—	60
Sand or gravel and clay	—	65
Clay	—	80
River mud	—	90
Soil	—	70
Stone riprap	—	65
MINERALS		
Asbestos	2.1 - 2.8	153
Barytes	4.50	281
Basalt	2.7 - 3.2	184
Bauxite	2.55	159
Borax	1.7 - 1.8	109
Chalk	1.8 - 2.6	137
Clay, marl	1.8 - 2.6	137
Dolomite	2.9	181
MINERALS (Continued)		
Feldspar, orthoclase	2.5 - 2.6	159
Gneiss, serpentine	2.4 - 2.7	159
Granite, syenite	2.5 - 3.1	175

FIGURE 4.1 SPECIFIC GRAVITIES AND WEIGHTS (cont.)

Substance	Specific Gravity	Weight, Lb/cu ft.
Greenstone, trap	2.8 - 3.2	187
Gypsum, alabaster	2.3 - 2.8	159
Hornblende	3.0	187
Limestone, marble	2.5 - 2.8	165
Magnesite	3.0	187
Phosphate rock, apatite	3.2	200
Porphyry	2.6 - 2.9	172
Pumice, natural	0.37 - 0.90	40
Quartz, flint	2.5 - 2.8	165
Sandstone, bluestone	2.2 - 2.5	147
Shale, slate	2.7 - 2.9	175
Soapstone, talc	2.6 - 2.8	169
STONE, QUARRIED, PILED		
Basalt, granite, gneiss	—	96
Limestone, marble, quartz	—	95
Sandstone	—	82
Shale	—	92
Greenstone, hornblende	—	107
BITUMINOUS SUBSTANCES		
Asphaltum	1.1 - 1.5	81
Coal, anthracite	1.4 - 1.7	97
Coal, bituminous	1.2 - 1.5	84
Coal, lignite	1.1 - 1.4	78
Coal, peat, turf, dry	0.65 - 0.85	47
Coal, charcoal, pine	0.28 - 0.44	23
Coal, charcoal, oak	0.47 - 0.57	33
Coal, coke	1.0 - 1.4	75
Graphite	1.9 - 2.3	131
Paraffine	0.87 - 0.91	56
Petroleum	0.87	54
Petroleum, refined	0.79 - 0.82	50
Petroleum, benzine	0.73 - 0.75	46
Petroleum, gasoline	0.66 - 0.69	42
Pitch	1.07 - 1.15	69
Tar, bituminous	1.20	75

FIGURE 4.2 PHYSICAL PROPERTIES OF METALS

	Melting Point, deg F	Boiling Point, deg F	Specific Gravity	Density, lb/ cu in.
Aluminum	1217	3272	2.67	0.09 - 0.1
Antimony	1166	2624	6.76	0.24
Beryllium	2345	5032	1.85	.066
Brass	1650	—	(7.8)	.28
			(8.6)	.31
Bronze	1650	—	(8.52)	.30
			(8.96)	.32
Cadmium	609	1409	8.65	.313
Cesium	83	1275	1.9	.069
Cobalt	2723	5250	8.55	.32
Copper	1981.4	5050	8.85	.319
German Silver	1850	—	(8.5)	.307
Gold	1945.5	3992	19.258	.695
Iridium	4280 - 313	3789	22.38	.808
Iron	2786	4442	7.9	.28
Iron, Cast	(1900)	—	7.22	.26
	(2200)			
Iron, Wrought	2700 - 2900	—	7.70	.278
Lead	621.3	(2900)	11.38	.411
		(3600)		
Lithium	354	2403	0.53	.019
Magnesium	1204	2048	1.75	.063
Manganese	2246	3452	8.0	.289
Mercury	-37.97	680	13.58	.490
Molybdenium	4760	8670	10.2	.368
Nickel	2642	—	8.8	.317
Niobium	4380	—	8.57	.31
Palladium	2822	7200	12.0	.433
Platinum	3191	7970	21.5	.776
Silver	1760.9	3550	10.51	.379
Sodium	208	1620	0.97	.035
Steel	2550	—	7.9	.28
Sulfur	239	833	2.07	.075
Tantalum	5250	—	14.1 - 16.1	.6
Tin	449.4	4118	7.35	.264
Titanium	3260	—	3.54	.16
Tungsten	6152	10700	18.8	.697
Zinc	786.9	1663	7.14	.258
Zirconium	3355	—	6.57	.23

FIGURE 4.2 PHYSICAL PROPERTIES OF METALS

Specific Heat	Atomic Weight	Heat Conductivity, Silver = 100	Electrical Conductivity, Silver = 100	Cubical Expansion by Heat from 130°F to 212°F	Typical Tensile Strength, psi
0.215	27.1	48	53.0	0.0070	18,000
.050	120.2	4.2	3.5	0.027 - 0.050	1,000
—	—	—	10	—	30-90,000
.092	—	(15)	23	0.0057	9,000
—	—	(30)	17	.0064	40,000
.086	—	—	—	(.0051)	3,000
—	—	—	—	(.0057)	25,000
.055	112.4	22.2	—	—	—
.052	132.9	—	—	—	—
.099	58.97	—	19.9	.0037	34,400
.093	63.57	89	99.5	.0051	30,000
.095	—	8	10 - 32	.0055	—
.032	197.2	53.2	76.7	.0044	14,000
.032	193.1	34	30	.0020	—
.113	55.84	11 - 18	9.9 - 17.0	.0036	39,500
.1298	—	11.9	(2.8) (1.4)	.0033	—
.1138	—	—	17	.0035	50,000
.031	207.20	8.2	7.6	.0088	(1,600) (2,400)
.79	6.94	—	—	—	—
.025	24.32	37.6	35.8	.0083	20,000
.115	54.93	—	—	—	—
.033	200.6	1.8	1.7	.0182	—
.061	95.95	34.6	34	—	54-100,000
.109	58.68	14	(14.5) (9.9)	.0038	(50,000) (100,000)
.065	92.9	—	—	—	—
.058	106.7	17	15	.0036	50,000
.032	195.2	17	(20) (10)	.0027	(30,000) (50,000)
.057	107.88	100	100	.0058	36,000
.295	22.99	—	—	—	—
.117	—	(6) (14)	16 3	.0041 .0030	50,000 20,000
.175	32.07	—	—	—	—
.036	181.5	—	9.9	.0024	—
.056	118.7	15.2	11.3	.0069	5,000
.130	48.1	—	13.7	—	—
.033	184.0	—	23.	—	500,000
.096	65.37	28.1	26	.0088	9,000 - 24,000
.069	91.22	—	4.3	—	—

FIGURE 4.3 CONDENSED TABULATION OF MECHANICAL PROPERTIES, ALLOYS OF STEEL, ALUMINUM AND MAGNESIUM

Alloy Steels

Commercial Designation	Form	Condition	Tensile Strength (psi)	Yield Strength 0.2% Offset (psi)	Elongation (% in 2 in.)	Hardness (Brinell)	Miscellaneous Information
SAE-4130	Sheet, plate, tube, bar & rod	$t < 0.188''$	95,000	75,000	25.5	197	Elongation & hardness is for 1″ rd.
SAE-4130	Plate and bar	Annealed $t < 1.50''$	65,000	45,000	28.2	156	Elongation & hardness is for 1″ rd.
SAE-4130	Sheet, plate, tube & rod	Heat-treated	150,000	135,000	16	306	
SAE-4340	Sheet	Heat-treated	236,000	212,000	10		Red. area—35%
18-8	Sheet and strip	Annealed	75,000	30,000			
18-8	Sheet and strip	Cold-rolled ½ hard	150,000	110,000			
18-8	Sheet and strip	Cold-rolled & heat-treated ½ hard	150,000	120,000			
18-8 (Type 304)	Sheet	Annealed	85,000	30,000	55-63	160	
18-8 (Type 304)	Sheet	Cold-rolled	185,000	160,000	8	400	Sample sheet
18-8 (Type 316)	Sheet	Annealed	90/100,000	35/45,000	50-60	170/200	
Inconel X	Sheet and strip (Gauges 0.025″ to 0.250″)	Annealed	100/140,000	40/80,000	35-60	140/241	
Inconel X	Sheet and strip (Gauges 0.025″ to 0.250″)	Annealed & aged	150/175,000	100/130,000	20-30	293/372	
Inconel X	Sheet	Annealed	120,000	55,000	50	175	Sample sheet
Inconel X	Sheet	Hot-rolled	188,000	130,000	23	355	Sample sheet

Aluminum Alloys

Commercial Designation	Form	Condition	Tensile Strength (psi	Yield Strength 0.2% Offset (psi)	Elongation (% in 2 in.)	Hardness (Brinell)	Miscellaneous Information
2024-T3 (24S-T3)	Sheet and plate	Heat-treated 0.250″	65,000	48,000	15	—	
2024-T4 (24S-T4)	Rolled bar, rod and shapes	Heat-treated 3.0″	62,000	40,000	16	—	
2024-T3 (24S-T3)	Tubing	Heat-treated	64,000	42,000	12	—	
2024-T81 (24S-T81)	Tubing	Heat-treated, cold worked and aged	68,000	60,000	—	—	
2024-T4 (24S-T4)	Extruded shapes	Heat-treated 0.250″	57,000	42,000	12	—	
2024-T81 (24S-T81)	Extruded shapes	Heat-treated, cold worked and aged	64,000	56,000	—	—	
2024-T36 (24S-T36)	Sheet	Wrought	72,000	57,000	14	130	
2024-T36 (24S-T36)	Alclad	Heat-treated & rolled	67,000	53,000	11	—	
2024-T86 (24S-T86)	Alclad	Artificially aged	70,000	66,000	6	—	
7075-T6 (75S-T6)	Sheet and plate	Heat-treated and aged 0.040-0.249″	77,000	67,000	8	—	
7075-T6 (75S-T6)	Rolled bar, rod & shapes	Heat-treated and aged—3.0″	77,000	66,000	7	—	
7075-T6 (75S-T6)	Extruded bar rod & shapes	Heat-treated and aged. Up to 0.249″	78,000	70,000	7	—	
7075-T6 (75S-T6)	Hand-forged stock	Cross section area —16 sq in.	75,000	64,000	9	—	
7075-T6 (75S-T6)	Die forgings	Thickness—4″	75,000	65,000	10	135	
7075-T6 (75S-T6)	Sheet	Wrought	82,000	72,000	11	150	

FIGURE 4.3 CONDENSED TABULATION OF MECHANICAL PEOPERTIES, ALLOYS OF STEEL, ALUMINUM AND MAGNESIUM (cont.)

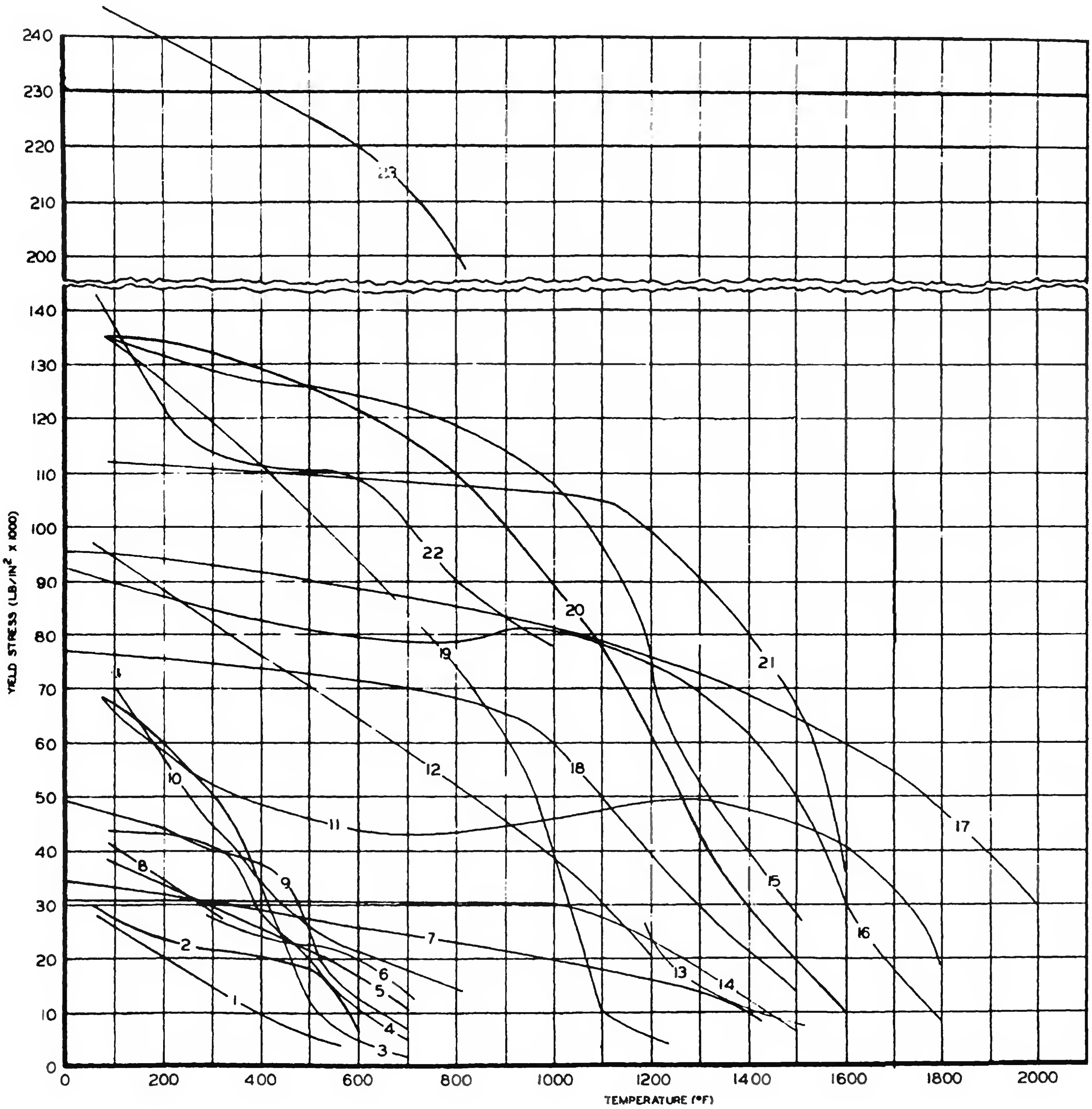
Magnesium Alloys

Commercial Designation	Form	Condition	Tensile Strength (psi)	Yield Strength 0.2% Offset (psi)	Compression Yield (psi)	Elongation (% in 2-in.)	Hardness (Brinell)	Miscellaneous Information
FS-1	Sheet	H 24	42/39,000	32/29,000	27/25,000	16-4	73	Dow desig.
FS-1	Sheet	O/F	37/32,000	22/18,000	16/12,000	21-12	56	
MH	Sheet	—	37/32,000	29/22,000		8-4	56	
AZ31B	Extruded rods, bars & solids	F	37,000	26,000	15,000	12	49	
	Sheet and plate	O	37,000	22,000	16,000	21	56	
		H 24	42,000	32,000	27,000	16	73	
O-1	Extrusion	—T 5	52/48,000	36/30,000	28/24,000	5-4	82	
ZK 60A	Extrusion	F	49/43,000	38/31,000		12-5	75	
		—T 5	51,000	42,000	30,000	10	82	
AZ63A	Casting	F	23,000	14,000	14,000	6	50	
		—T 6	40,000	19,000	19,000	5	73	
EK 30A	Casting	—T 6	20,000	15,000		3		High-temp. alloy
		@ 400 °F	17,000	10,000		15		
HK31XA	Casting	—T 2	37,000	18,000		8		High-temp. alloy
		@ 400 °F	26,000	14,000		17		
		@ 600 °F	20,000	12,000		22		
AZ91A	Die casting	F	33,000	22,000	20,000	3	60	
HM21XA	Extrusion	—T 5	38,000	30,000	24,000	7		
		@ 400 °F	21,000	19,000				
		@ 600 °F	15,000	13,000				

O = annealed
H 24 = hard rolled
F = as fabricated

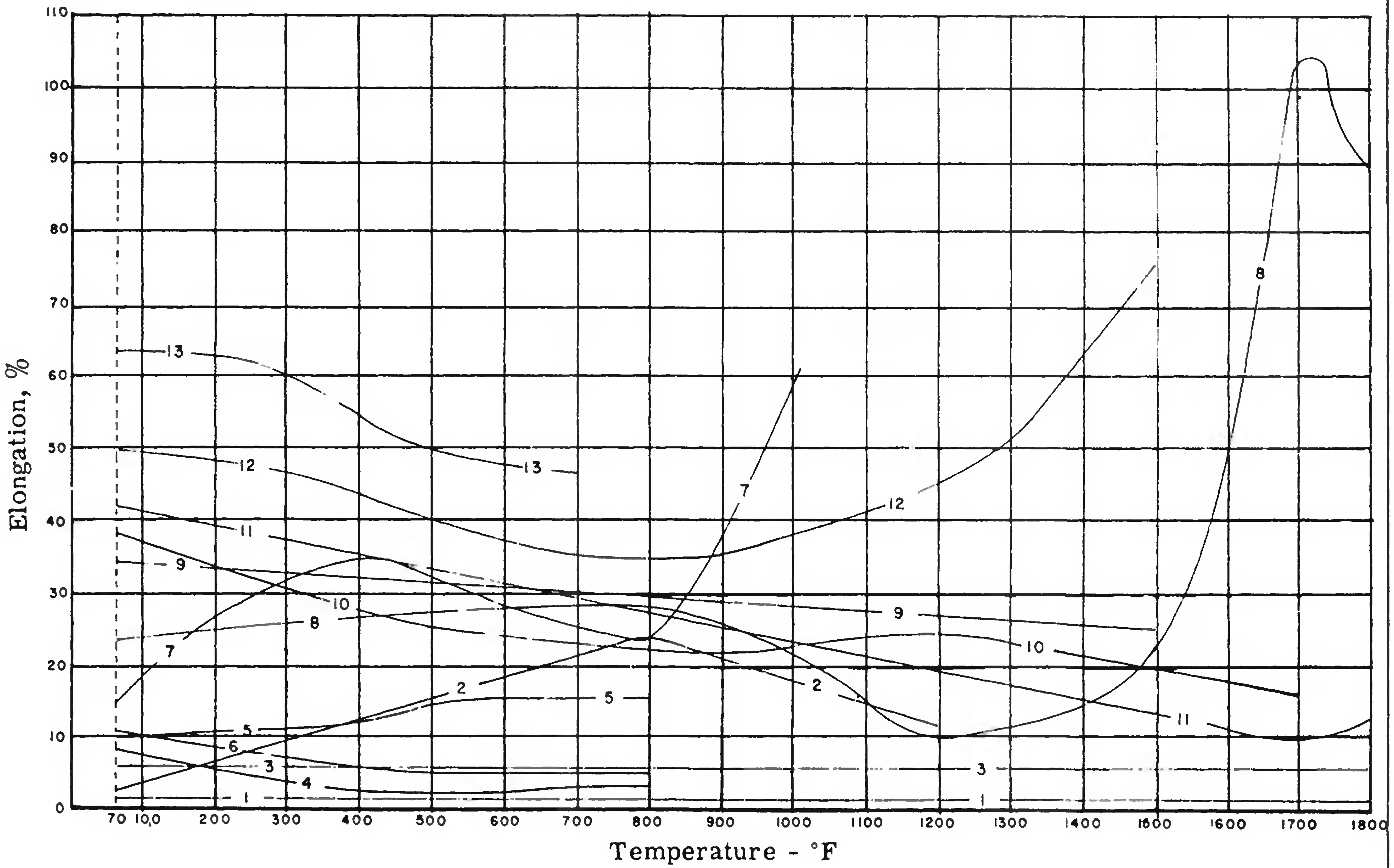
—T 5 = aged
—T 2 = as cast and stabilized
—T 6 = solution heat treated and aged

FIGURE 4.4 YIELD STRESS VS TEMPERATURE FOR REPRESENTATIVE MATERIALS



1. Magnesium
2. HK31-H24 Magnesium
3. 7075-T6 Aluminum
4. 4X2219-T6 Aluminum
5. X-HM21XA-T8
6. HK31-T6 Mag-Thorium
7. Beryllium
8. Laminated Plastic
9. 2024-T4 Aluminum
10. Comm. Titanium Annealed
11. Hastelloy
12. Beryllium
13. 316 S.S.
14. Nimonic 75
15. 4130 Steel (HT-135000 Psi)
16. Nimonic 95
17. Molybdenum
18. 4130 Steel Annealed
19. Titanium Alloy
20. 18 -8 Stainless Steel (1/2 Hard)
21. Inconel X
22. Titanium Alloy 6A1-4V
23. 4340 Steel

FIGURE 4.5 ELONGATION VS TEMPERATURE FOR REPRESENTATIVE MATERIALS

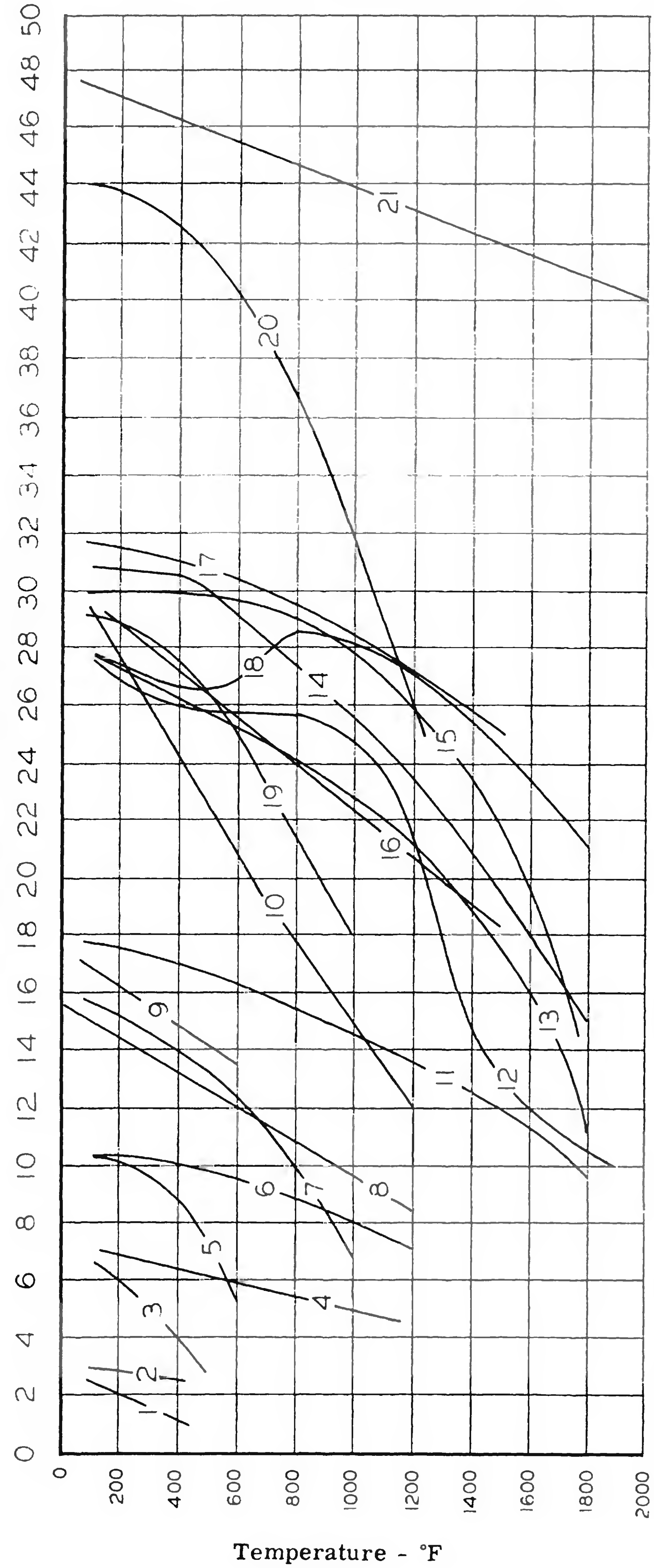


1	Graphite	4	304 Stainless - Full Hard	7	Titanium 150A	10	Copper
2	Beryllium	5	4340	8	Inconel X	11	Iron
3	Molybdenum	6	17-7Ph.	9	Tantalum	12	347 Stainless
						13	304 Stainless - Annealed

FIGURE 4.6 EFFECT OF TEMPERATURE ON DUCTILITY FACTORS OF REPRESENTATIVE AIRCRAFT METALS

Material	Notched Static Tensile			Charpy Impact		
	Reduction of area at Root of Notch %		Temperature effect, Per cent	Ft lb of Energy		Temperature effect, Per cent
	Room	-320°F		Room	-320°F	
7075 - T6	2.25	2.25	0	4.0	6.0	+50
2024 - T4	7.0	6.5	-7	5.5	6.0	+10
18-8 Stainless	11.5	7.25	-37	24.7	30.3	-25
Titanium	12.5	5.0	-60	14.5	6.6	-54
FS - 1h	11.25	4.0	-65	4.2	2.0	-52
SAE 2330(150,000 psi)	22.0	6.75	-70	35.3	16.8	-50
SAE 4340(150,000 psi)	17.0	6.25	-61	38.7	16.4	-57
SAE 4340(230,000 psi)	3.5	2.75	-21	19.0	7.4	-60
Hy-Tuf(230,000 psi)	7.5	2.5	-66	24.8	9.7	-60
SAE 8630(150,000 psi)	13.25	3.25	-75	39.1	5.0	-87

FIGURE 4.7 MODULUS OF ELASTICITY VS. TEMPERATURE FOR REPRESENTATIVE MATERIALS
(Approximate Average Values are given)

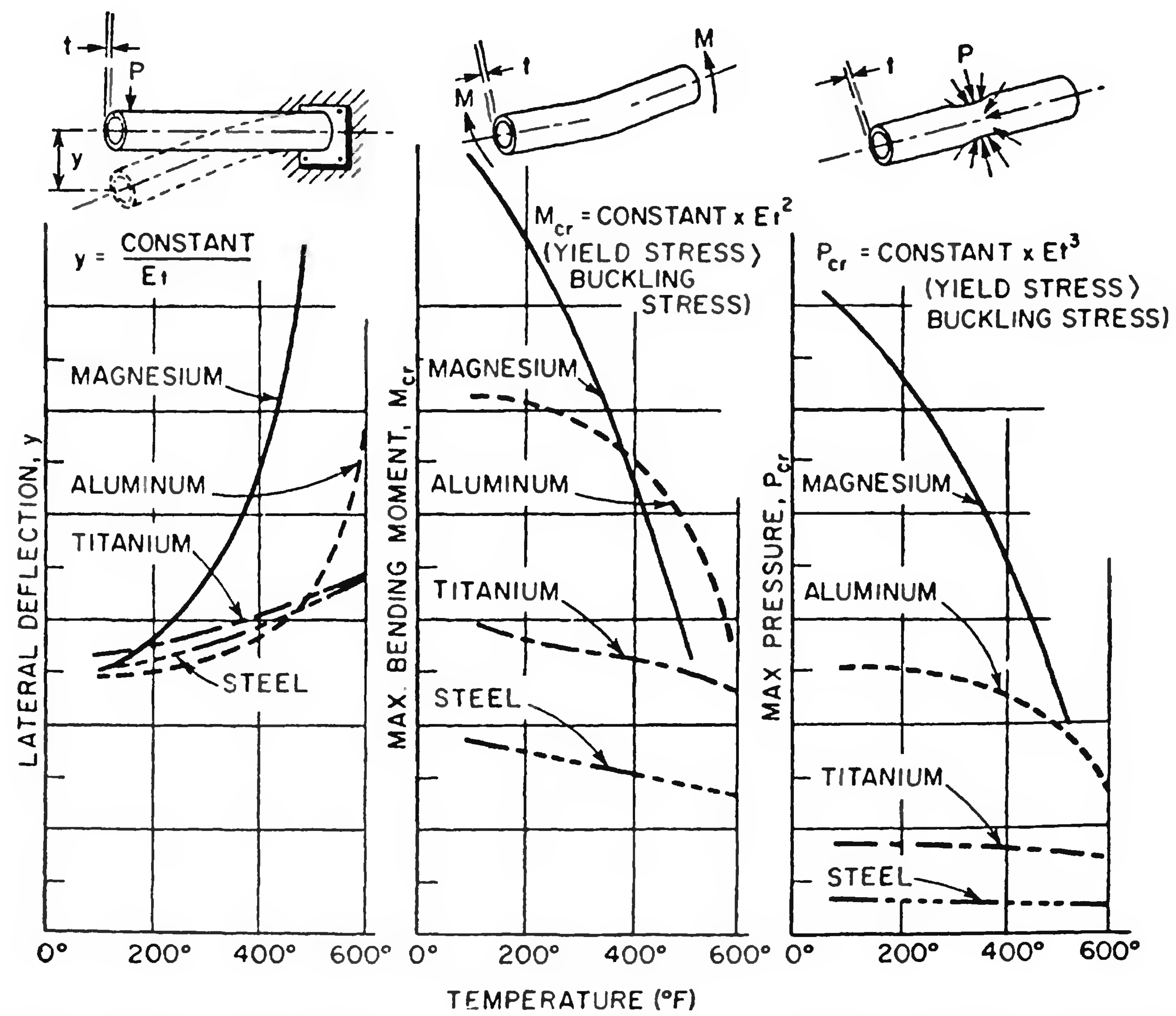


1 Fiberglas
2 Laminated Plastic
3 Magnesium
4 Magnesium
5 Aluminum
6 Aluminum
7 Titanium
8 Titanium
9 HK 31-T Mag.
10 4130 (Normal & 150000 Utl)
11 Copper
12 Nimonic 75
13 25-20-2%S Steel
14 Inconel X
15 Nimonic 95
16 18-8 Stainless Steel
17 Hastelloy
18 Nickel
19 Carbon Steel (C1030)
20 Beryllium
21 Molybdenum

FIGURE 4.8 LOW TEMPERATURE MODULUS OF ELASTICITY IN TENSION OF REPRESENTATIVE AIRCRAFT METALS

Material	Modulus of Elasticity (E x 10^6 psi)			
	-25°C -77°F	-78°C -108°F	-196°C -320°F	Increase % +25°C -196°C
Aluminum Alloy, 2024-T4	10.87	11.11	11.97	10.1
Aluminum Alloy, 7075-T6	10.27	10.75	11.55	12.4
Magnesium Alloy, FS-1h	6.36	6.83	7.30	14.7
Titanium, Commercially Pure	16.7	17.5	18.96	11.3
Steel, SAE 2330 (150,000 psi)	29.18	–	31.59	8.3
Steel, SAE 8630 (150,000 psi)	29.77	–	32.38	8.8
Steel, SAE 4340 (150,000 psi)	30.9	–	31.8	2.9
Steel, SAE 4340 (230,000 psi)	30.7	–	30.9	0.6
Steel, SAE (High Temp.) (230,000 psi)	29.8	–	31.3	5.0
Steel, SAE 18.8 (210,000 psi)	23.57	–	27.66	17.5

FIGURE 4.9 STIFFNESS-WEIGHT COMPARISON FOR THIN WALLED CYLINDERS OF EQUAL WEIGHT (t — VARIABLE DIMENSION)



CASE I LATERAL DEFLECTION CASE II BENDING CASE III EXTERNAL PRESSURE

FIGURE 4.10 YIELD STRENGTH-WEIGHT RATIO VS. TEMPERATURE FOR REPRESENTATIVE MATERIALS

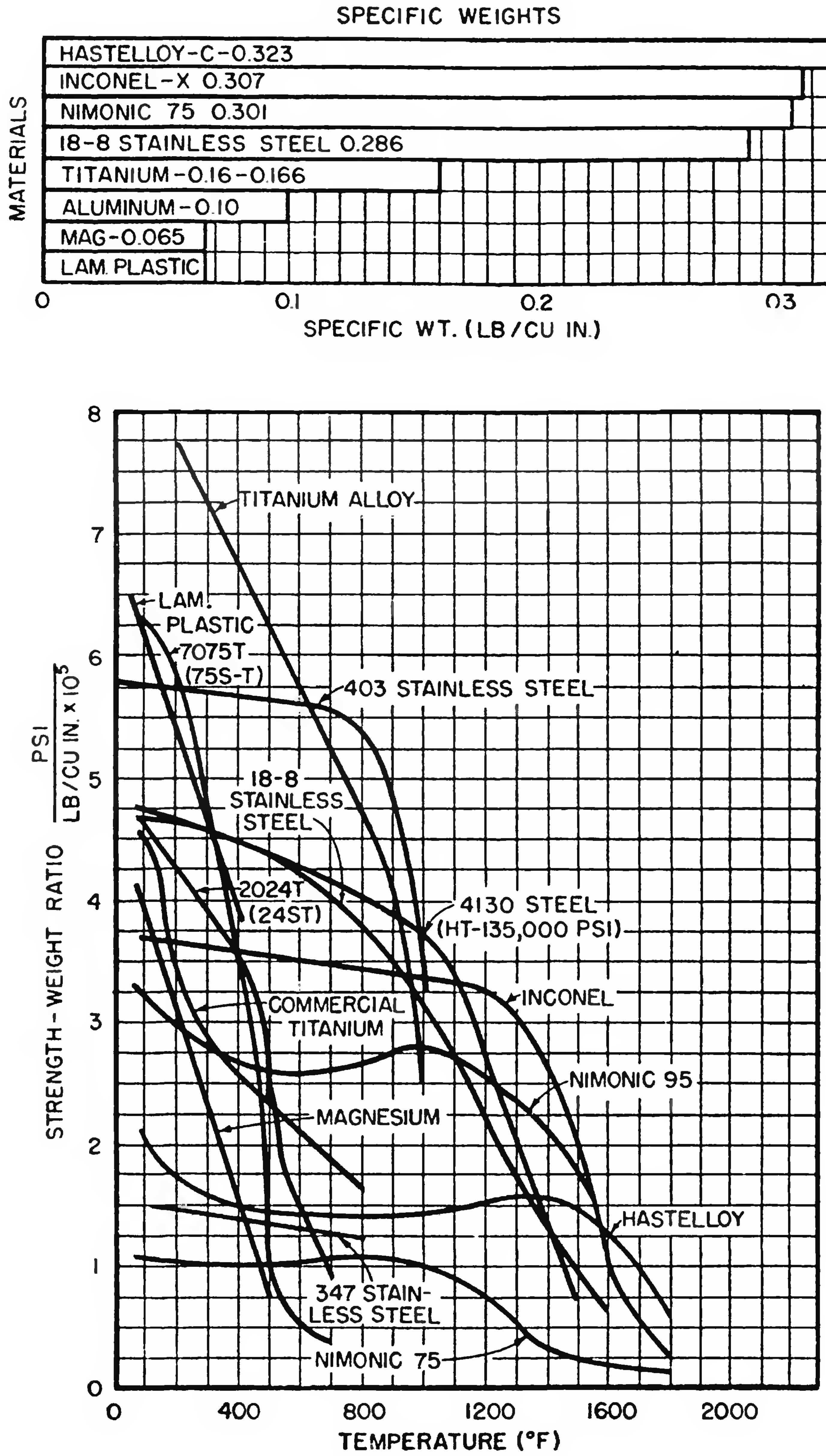
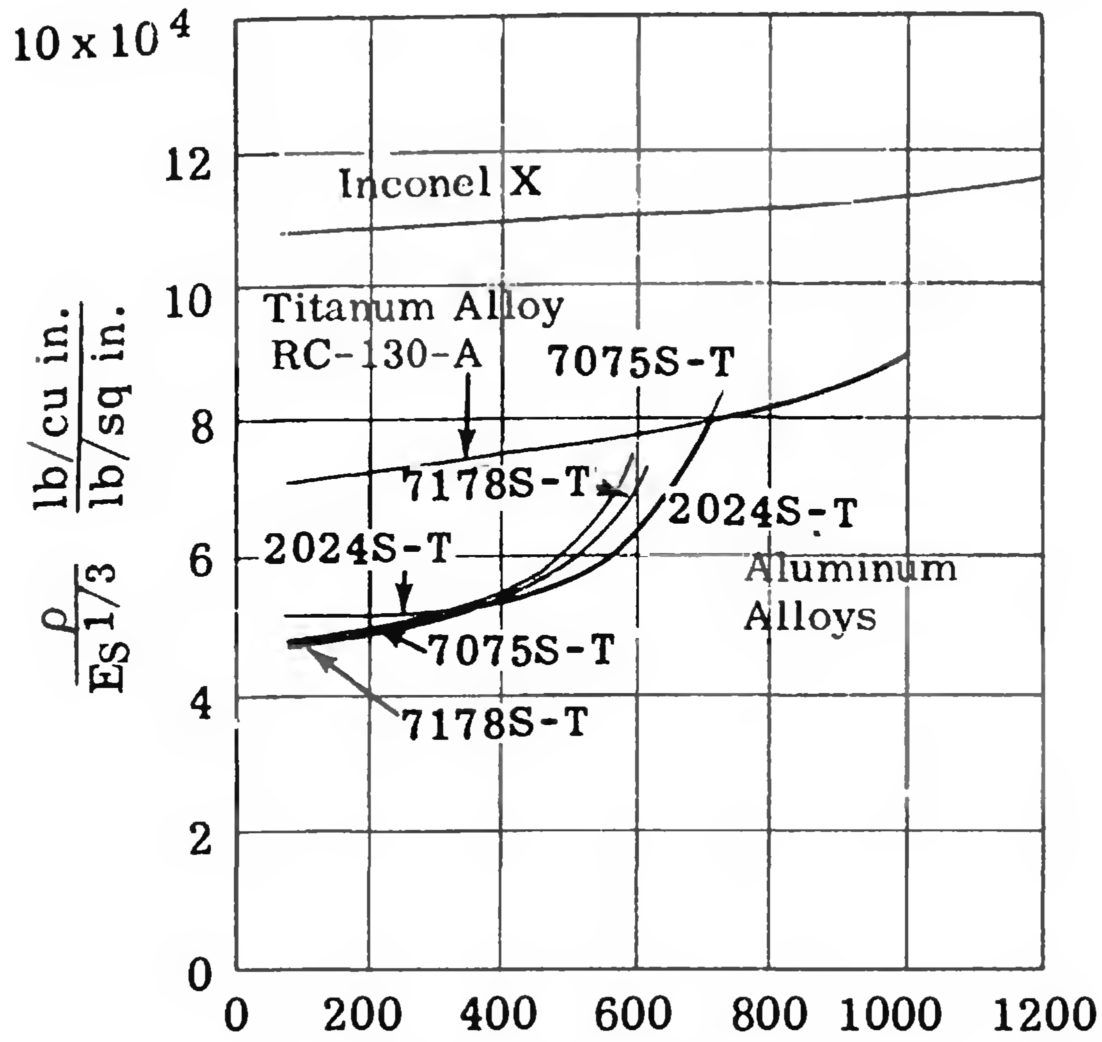
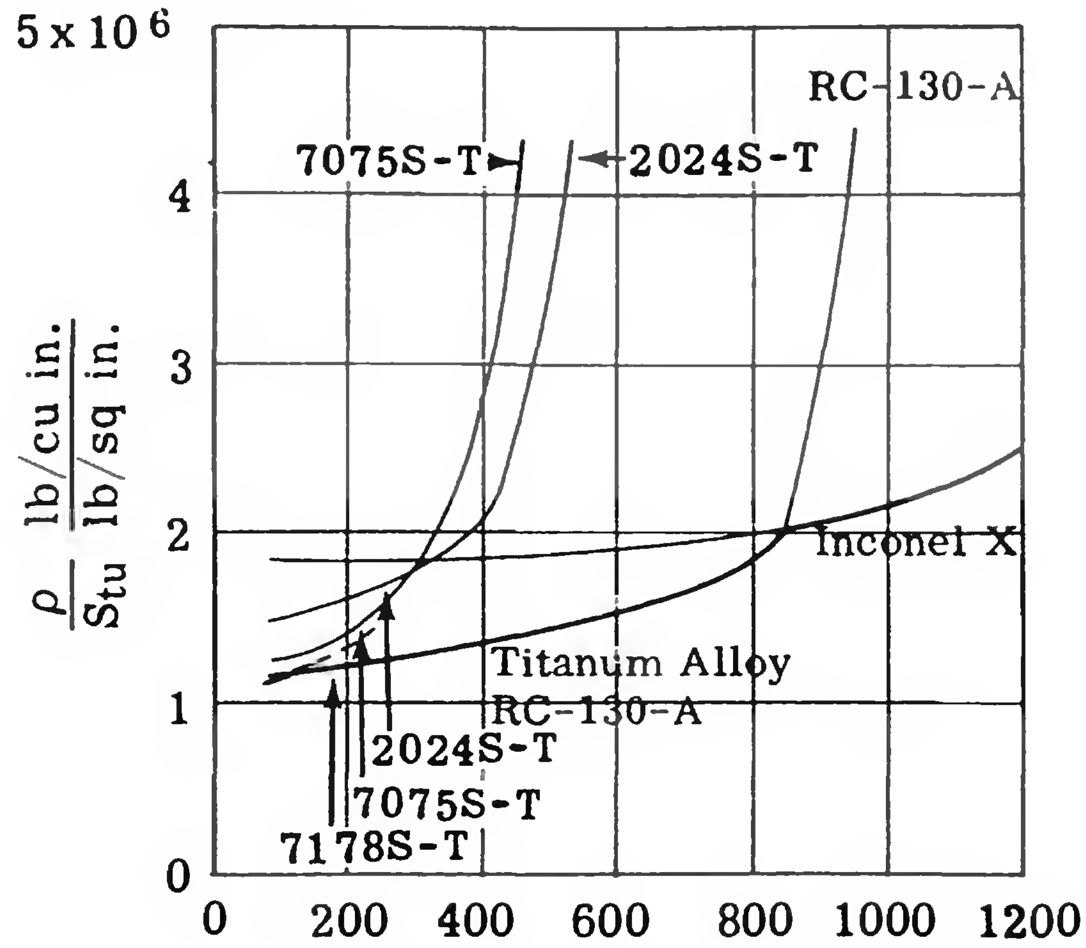


FIGURE 4.11 STRENGTH-WEIGHT RATIO CHARACTERISTICS VS. TEMPERATURE FOR REPRESENTATIVE MATERIALS



Weight-strength ratios for short-time compressive and shear loading of various materials (ρ = Density, E_s = secant modulus at yield). In contrast to the tension case, aluminum alloys are superior to titanium up to 700°F (Gerard).



Weight-strength ratios for short-time tension loading of various alloys (ρ = density, S_{tu} = ultimate tensile strength). Note that titanium alloy RC-130-A is efficient at room temperature and retains this efficiency up to 800°F (Gerard).

FIGURE 4.12 COMPRESSIVE STRESS-STRAIN CURVES AT ROOM TEMPERATURE

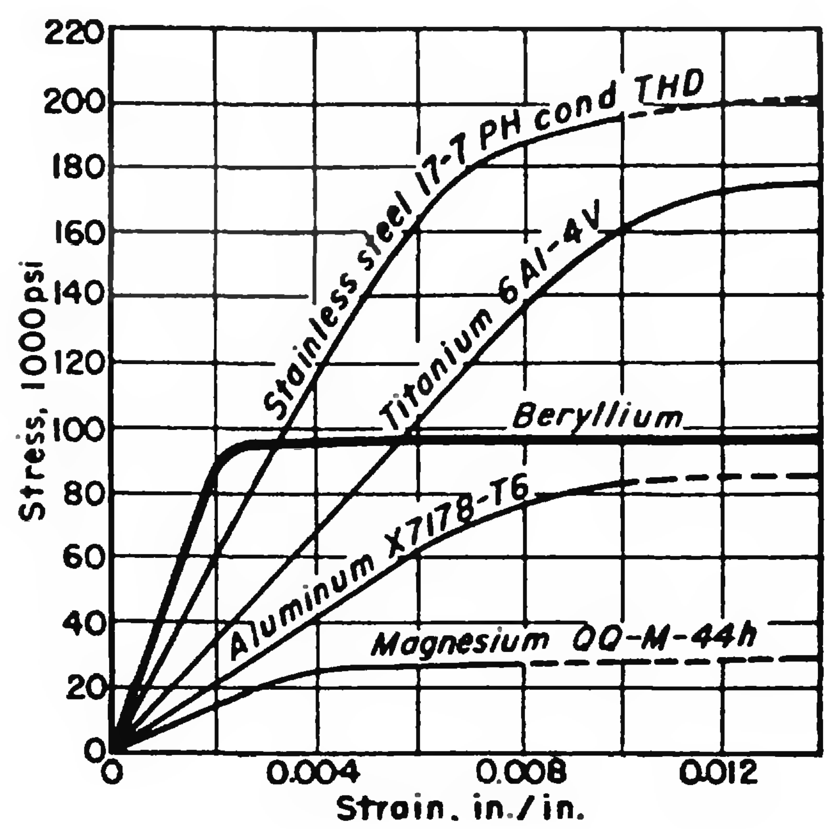


FIGURE 4.13 RELATIVE VALUE OF MATERIALS AS SHEET-STIFFENER PANELS

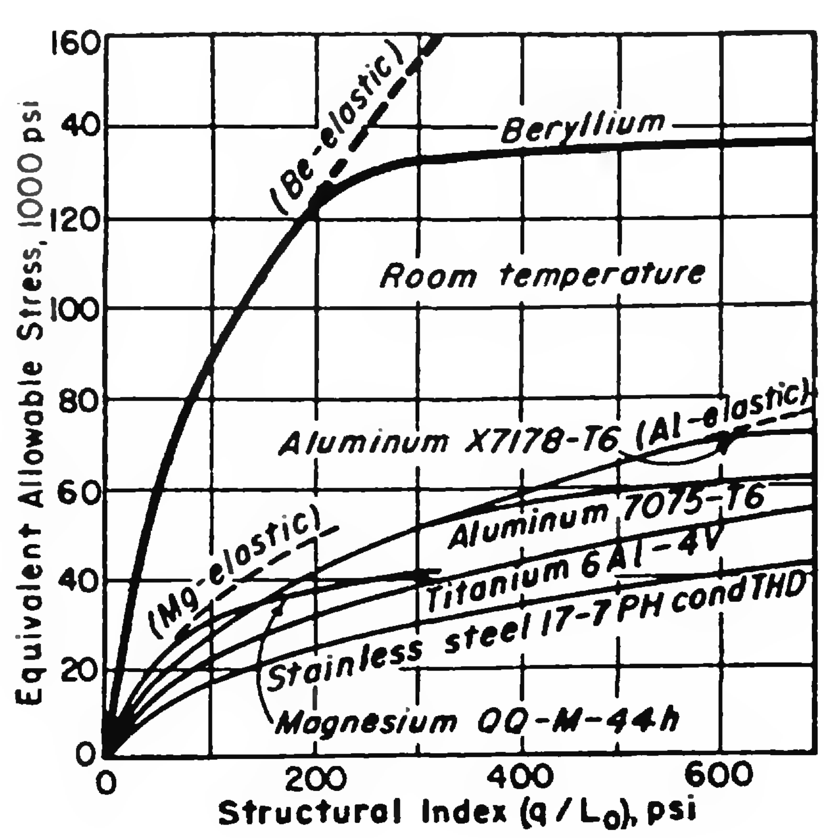
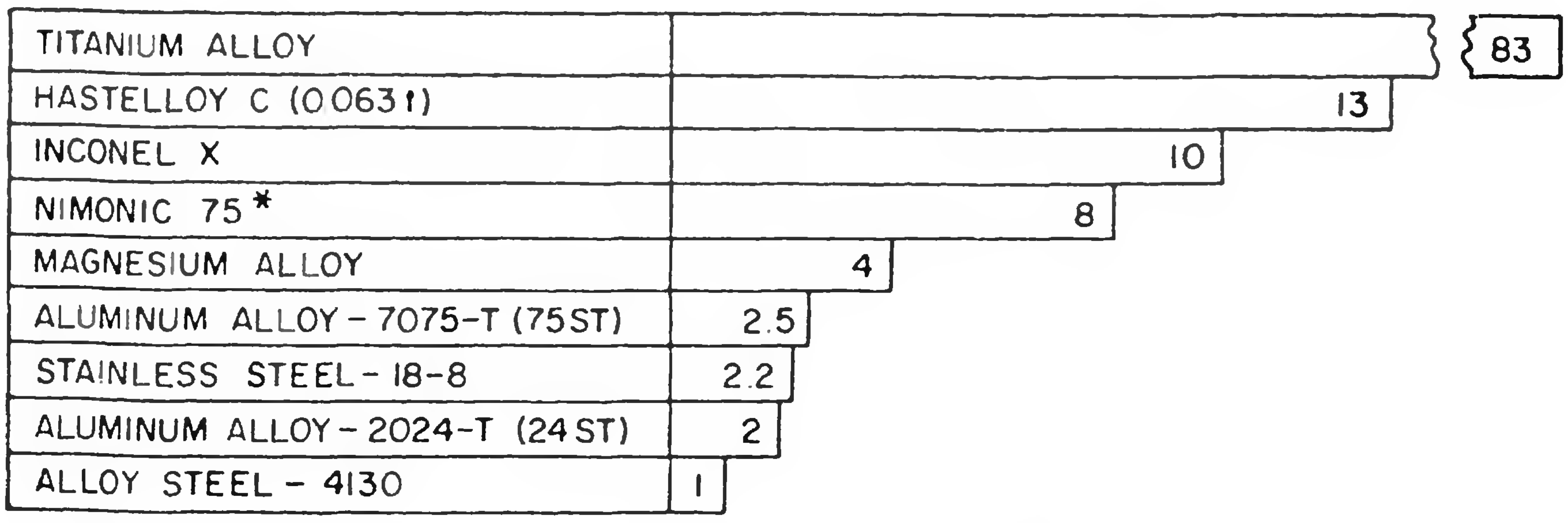


FIGURE 4.14 STRENGTH-COST RATIO VS. TEMPERATURE FOR REPRESENTATIVE MATERIALS



APPROXIMATE RELATIVE COST: 4130 STEEL = 22.4 ¢ PER LB

COSTS BASED ON 36" x 144" x 0.065" SHEET IN 1000-LB LOTS

* 36" x 120" x 0.060" SHEET

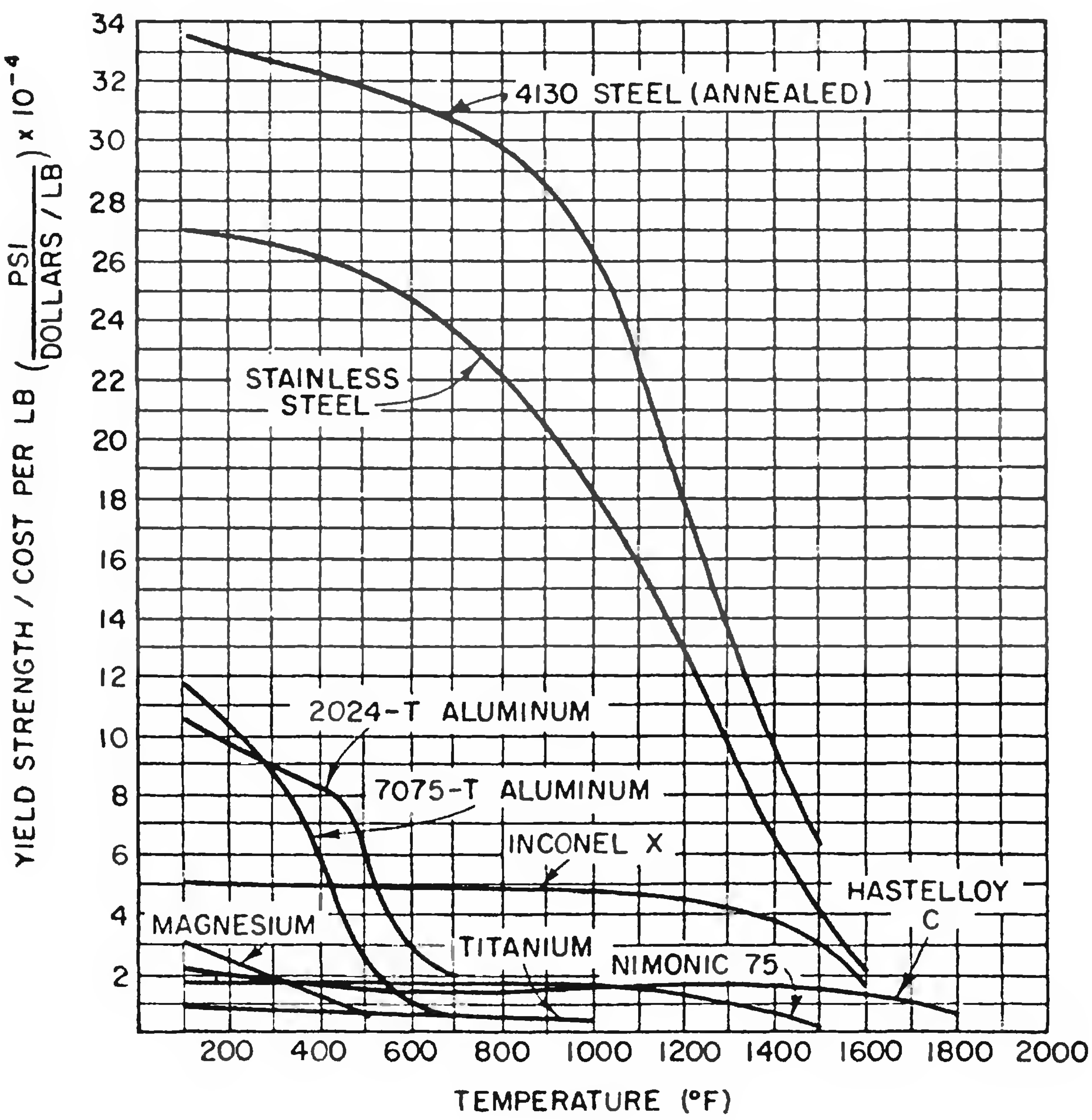


FIGURE 4.15 MEAN COEFFICIENT OF THERMAL EXPANSION VS. TEMPERATURE FOR REPRESENTATIVE MATERIALS

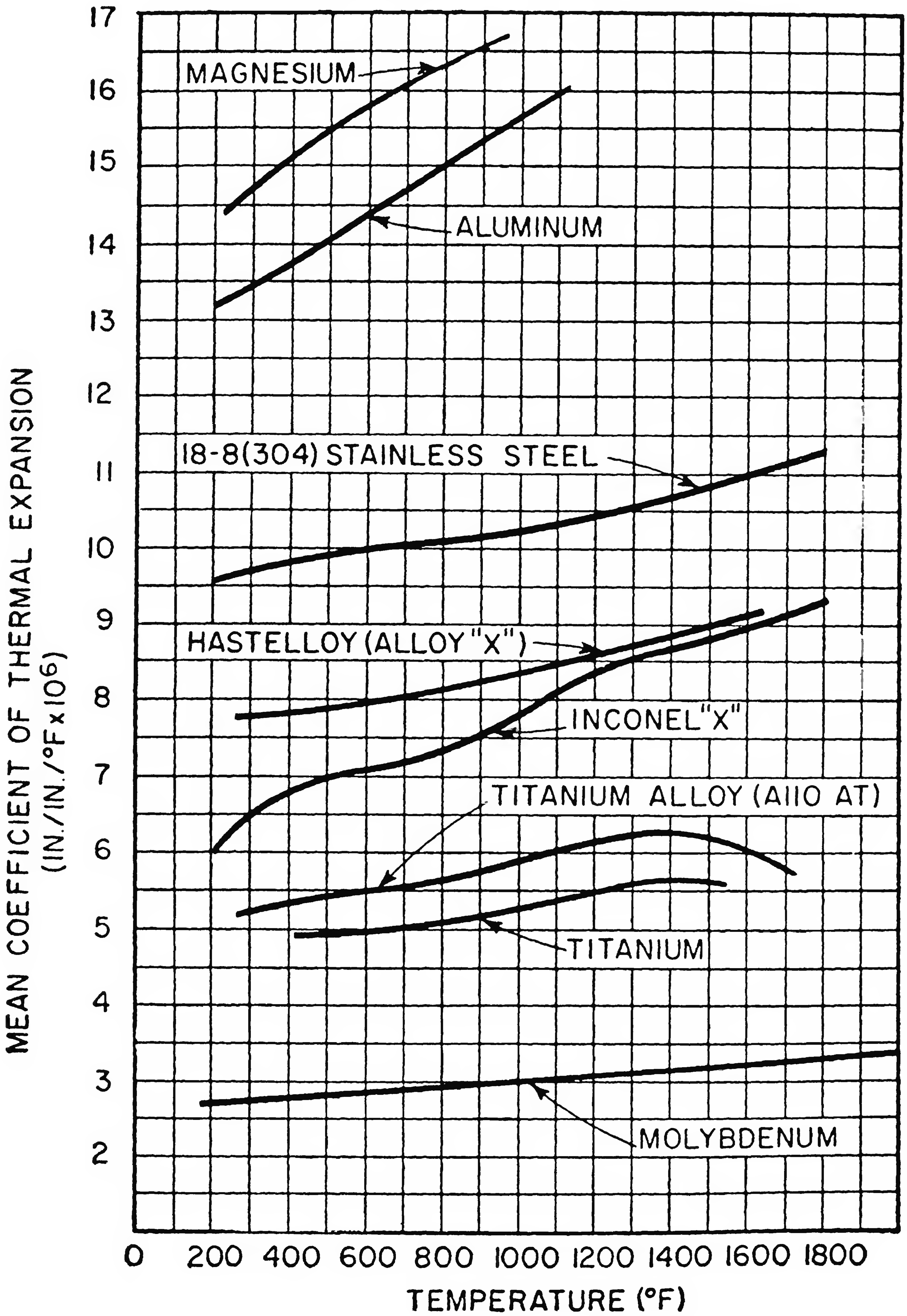


FIGURE 4.16 THERMAL LINEAR EXPANSION FOR REPRESENTATIVE MATERIALS FOR 70 - 200 F RANGE

Material	Coefficient of Linear Expansion (0.000001-in/in./°F)	Material	Coefficient of Linear Expansion (0.000001-in./in./°F)
Aluminum	12.34	Mylar (polyester film)	15.00
Aluminum bronze	9.16	Nickel	6.95
Bakelite	12.20	Nickel silver	10.20
Barium	10.50	Niobium (Columbium)	4.00
Beryllium	6.80	Nylon, Molding	100.00
Beryllium copper	9.30	Paraffin (61 to 100 deg F)	72.00
Brass	9.57	Phenolic paper-fiber laminate	19.00
Bronze	9.86	Phosphor bronze	9.40
Cadmium	16.60	Platinum	4.79
Carbon	0.67	Plexiglass (acrylic plastic)	90.00
Cellulose acetate	160.00	Porcelain	2.30
Chromium	3.40	Polyethylene	100.00
Cobalt	7.00	Polystyrene	80.00
Concrete	8.00	Quartz, natural (parallel to axis)	4.40
Copper	8.87	Quartz, natural (perpendicular to axis)	2.90
Epoxy glass-fiber laminate	6.00	Rubber	42.8
Ethyl cellulose	200.00	Rubber, hard (Ebonite)	47.00
German Silver	10.20	Rubber, hard (Vulcanite)	40.00
Glass	5.00	Selenium	20.00
Glass, fused quartz	0.32	Silicon	3.00
Glass, Pyrex	1.80	Silver	10.79
Gold	7.86	Solder	13.88
Graphite	4.40	Stainless steel, 18-8, Type 302	10.00
Ice	28.3	Steel	6.36
Indium	18.33	Stellite	8.56
Invar	0.44	Tantalum	3.60
Iridium	3.56	Tin	11.63
Lead	15.71	Titanium	3.96
Magnesium	14.30	Tungsten	2.20
Manganese	12.80	Urea, molding	25.00
Melamine, molding	23.00	Vinyl	70.00
Mercury	10.00	Wood - oak (perpendicular to fiber)	3.00
Molybdenum	3.05	Zinc	14.70
Monel	7.77	Zirconium	3.50

FIGURE 4.17 THERMAL CONDUCTIVITY VS. TEMPERATURE FOR REPRESENTATIVE MATERIALS

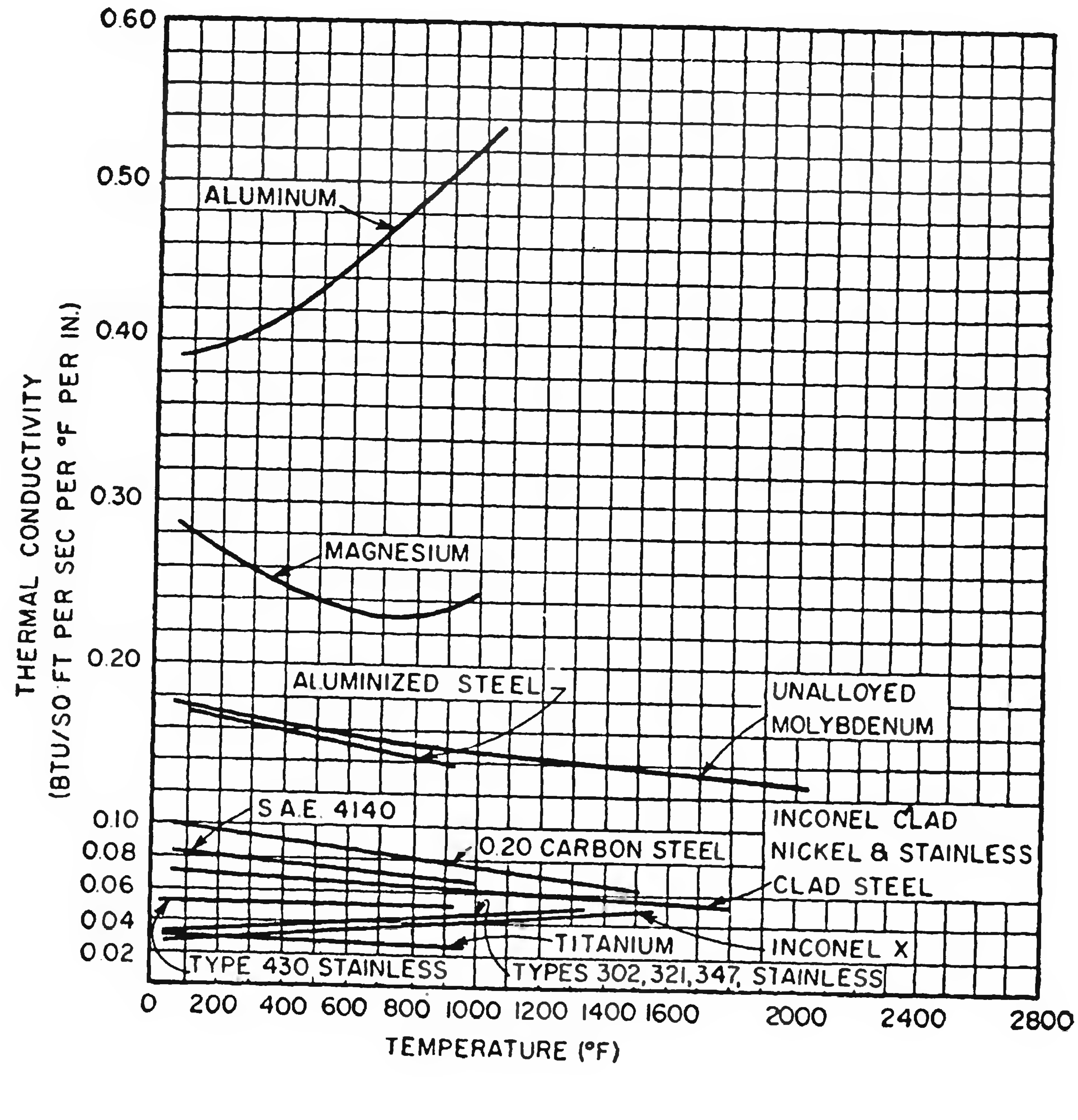


FIGURE 4.18 HEAT CONDUCTION DATA FOR VARIOUS MATERIALS AT APPROXIMATELY 149°F (65°C)

Material	Density lb/cu in.	Thermal Conductivity, K; BTU/(hr.)(sq ft)/°F/in.
Silver	0.380	2900.0
Copper	.322	2640.0
Gold	.696	2050.0
Aluminum, pure	.098	1500.0
Aluminum, 6063 S	.100	1390.0
Magnesium	.063	1090.0
High-beryllia ceramics	0.109 - 0.136	464 - 1
Red brass	0.316	764
Yellow brass	.310	655
Beryllium copper	.297	474
Pure iron	.284	518
Phosphor bronze	.318	355
Soft steel	.284	322
Monel	.318	246
Lead	.409	227
Hard Steel	.284	178
Stainless Steel		115 - 150
Titanium		105 - 120
Aluminum Alloys		850
Steatite	.094	163
Pyrex	.094	8.73
Grade A Lava	.085	8.20
Soft glass	.094	6.83
Water	.0361	4.55
Mica	.101	4.09
Paper-base phenolic	.0497	1.91
Plexiglas	.043	1.28
Casting resin	.045	1.26
Polystyrene	.038	0.730
Plastics		1 - 5
Brick, soft		5.00
Brick, hard		9.00
Concrete, average		12.00
Rubber, expanded		.21
Soil (Average, Moist)		10.00
Maple	.025	1.15
Pine	.018	0.803
Balsa Wood, treated		.35
Sawdust, wood		.41
Shavings, wood		.40
Wood, 16% Moisture, across grain		
Cypress		.75
Fir, Douglas		.76

FIGURE 4.18 HEAT CONDUCTION DATA FOR VARIOUS MATERIALS AT APPROXIMATELY 149°F (65°C) (cont.)

Material	Density lb/cu in.	Thermal Conductivity, K; BTU/(hr.)(sq ft)/°F/in.
Mahogany		1.01
Oak		1.14
Pine, hard		1.07
Wood Pulp Board		0.49
Glass wood	0.001	.276
Air	0.000043	.192
Styrofoam	0.00116	0.23 -0.30
Flotofoam	0.00046	0.18 -0.21
Polyvinyl Chloride Foam	0.0029	0.23
GE Phenolic Foam	0.00173 - 0.0029	.24
GE Phenolic Foam	0.0041 - 0.0058	.28
Hair Felt	0.0052	.26
Rock Wool	0.0035	.27
Corkboard	0.0041	.28
Fiberboard	0.011	.34
Alfol, flat		.25
Armorak		.29
Asbestos, packed		1.62
loose		1.07
mill board		.84
Balsum Wool		.25
Celotex, board		.31
low temp.		.30
Cork, ground, loose		.30
Cotton, loose		.39
Felt, from cattle hair		.26
between paper		.27
Fibrofelt		.32
Glass wool, batts		.27
high grade		.24
Hairinsul		.27
Insulex		.60
Insulite, low temp.		.29
Kapok		.24
Magnesia board with Asbestos		.51
Masonite		.33
Mineral Wool - loose		.27
Batts, loose		.29
Batts, firm		.30
Onasote (Rubber)		.20
Palco Wool		.25
Paper		.27
"Rock Cork", high grade		.33
Temlock		.33

FIGURE 4.19 ELECTRICAL CONDUCTIVITY OF METALS

	Relative Conductivity[1]	Temp. Coef.[2] of Resistance
Aluminum (1100; pure)	59.0	0.0049
Aluminum (alloys):		
Soft-annealed	45 - 50	
Heat-treated	30 - 45	
Brass	28.0	0.002 - 0.007
Cadmium	19.0	
Chromium	55.0	
Cobalt	16.3	
Constantin	3.24	0.00002
Copper (hard drawn)	89.5	0.004
Copper (annealed)	100.0	
Everdur	6.0	
German Silver (18%)	5.3	0.00019
Gold	65.0	
Iron (pure)	17.7	0.006
Iron (cast)	2 - 12	
Iron (wrought)	11.4	
Lead	7.0	0.0041
Manganin	3.7	0.00002
Mercury	1.66	0.00089
Molybdenum	33.2	0.0033
Monel	4.0	0.0019
Nichrome	1.45	0.00017
Nickel	12 - 16	0.005
Phosphor Bronze	36.0	0.004
Platinum	15.0	
Silver	106.0	0.004
Steel	3 - 15	
Tin	13.0	0.0042
Tungsten	28.9	0.0045
Zinc	28.2	0.0035

Approximate relations:

An increase of 1 in A. W. G. or B. and S. wire size increases resistance 25%.

An increase of 2 increases resistance 60%.

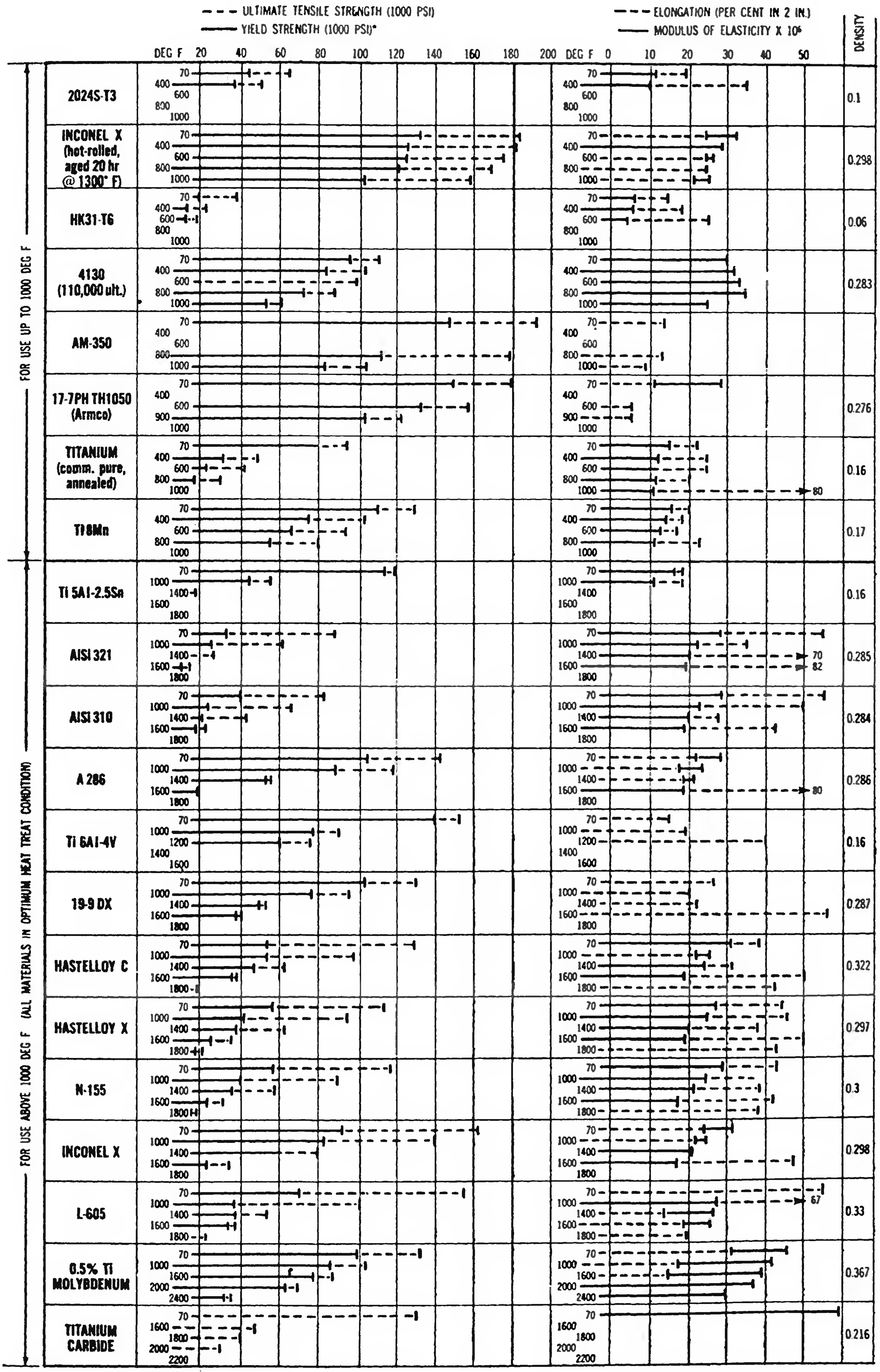
An increase of 3 increases resistance 100%.

An increase of 10 increases resistance 10 times.

[1] At 20°C., based on copper as 100.

[2] Per °C. at 20°C.

FIGURE 4.20 THERMAL LIMITS OF METAL



*OFFSET IS 0.2 PER CENT OF YIELD STRENGTH

FIGURE 4.21 PROPERTIES OF WROUGHT ALUMINUM ALLOYS

Alloy		Condition	Relative Resistance to Corrosion	Relative Formability	Relative Machinability
New	Old				
EC-0	EC-0	Annealed	A	A+	B
EC-H19	EC-H19	Hard	A	B-	B
1100-0	2S-0	Annealed	A	B+	B
1100-H18	2S-H18	Hard	A	B-	B
3003-0	3S-0	Annealed	A	A+	B
3003-H18	3S-H18	Hard	A	C+	B
2011-T3	11S-T3	Heat-treated	D	C-	A+
2011-T8	11S-T8	H.T., C.W. and aged	C	D	A+
024-T3	24S-T3	Heat-treated	C	C-	A
2024-T36	24S-T36	H.T. and C.W.	C	D+	A
5052-0	52S-0	Annealed	A	A+	B
5052-H38	52S-H38	Hard	A	C+	B
5154-0	A54S-0	Annealed	A	B+	C
5154-H34	A54S-H34	Hard	A	B+	C
6061-T4	61S-T4	Heat-treated	A	B	B
6061-T6	61S-T6	H.T. and aged	A	B-	B
6063-T5	63S-T5	Extruded and aged	A	B	B
7075-T6	75S-T6	H.T. and aged	C	D	A

FIGURE 4.22 PROPERTIES OF ALUMINUM CASTING ALLOYS

Alloy	Condition	Relative Resistance to Corrosion	Relative Machinability	Relative Weldability		Ultimate Tensile Strength, 1000 psi
				Arc	Spot	
SAND-CASTING ALLOYS						
43-F	As cast	B	B	A	A	19
195-T6	H.T. and aged	C	B	C	C	36
214-F	As cast	A	B	C	C	25
220-T4	Heat-treated	A	B	D	D	48
319-F	As cast	D	B	B	B	27
355-T6	H.T. and aged	B	B	B	B	35
356-T6	H.T. and aged	B	B	B	B	33
PERMANENT-MOLD CASTINGS						
43-F	As cast	B	B	A	A	23
D132-T5	Aged only	C	B	B	B	36
142-T571	Aged only	C	B	C	C	40
B195-T4	Heat-treated	C	B	C	C	37
333-F	As cast	C	B	C	C	34
355-T6	H.T. and aged	B	B	B	B	42
356-T6	H.T. and aged	B	B	B	B	38
DIE-CASTING ALLOYS						
13	As cast	B	C	D	D	39
85	As cast	C	B	D	D	40
360	As cast	B	B	D	D	44
380	As cast	C	B	D	D	43

FIGURE 4.21 PROPERTIES OF WROUGHT ALUMINUM ALLOYS

Relative Suitability for Being Brazed	Relative Weldability: Arc	Relative Weldability: Spot	Ultimate Tensile Strength, 1000 psi	Tensile Yield Strength, 1000 psi	Elongation in 2 in. Sheet Specimen 1/16 Thick, Per Cent	Shear Strength, 1000 psi	Endurance Limit, 1000 psi	Brinell Hardness 500-Kg Load 10-Mm Ball	Electrical Conductor % Int'l Annealed Copper Standard
A	A	B	12	4					62
A	A	A	27	24					61
A	A	B	13	5	35	9	5	23	59
A	A	A	24	22	5	13	9	44	57
A	A	B	16	6	30	11	7	28	50
A	A	A	29	27	4	16	10	55	40
D	D	D	55	43		32	18	95	40
D	D	D	59	45		35	18	100	
D	B	B	70	50	18	41	20	120	30
D	B	B	72	57	13	42	18	130	29
C	A	B	28	13	25	18	17	45	35
C	A	A	42	37	7	24	19	85	35
D	A	B	35	18	27	22	17	58	32
D	A	B	42	33	13	24	19	73	31
A	A	A	35	21	22	24	14	65	40
A	A	A	45	40	12	30	14	95	40
A	A	A	27	21	12	17	10	60	55
D	D	B	83	73	11	48	23	150	30

FIGURE 4.22 PROPERTIES OF ALUMINUM CASTING ALLOYS

Tensile Yield Strength, per cent	Elongation in 2 inches, Round Specimen 1/2-Inch Diameter per cent	Compressive Yield Strength, 1000 psi	Shear Strength, 1000 psi	Endurance Limit, 1000 psi	Brinell Hardness 500-Kg Load 10-Mm Ball	Electrical Conductor International Annealed Copper Standard
8	8.0	9	14	8.0	40	37
24	5.0	25	30	7.5	75	33
12	9.0	12	20	7.0	50	35
26	16.0	27	34	8.0	75	21
18	2.0	19	22	10.0	70	27
25	3.0	26	28	9.0	80	36
24	3.5	25	26	8.5	70	39
9	10.0	9	16		45	37
28	1.0	28	28	13.5	105	26
34	1.0	34	30	10.5	105	34
19	9.0	20	30	9.5	75	33
19	2.0	19	27	14.5	90	26
27	4.0	27	34	10.0	90	36
27	5.0	27	30	13.0	85	39
21	2.0		25	19.0		31
24	3.0		26	23.0		30
27	3.0		28	19.0		28
26	2.0		28	20.0		23

FIGURE 4.23 PHYSICAL PROPERTIES OF XA78S-T6 ALUMINUM ALLOY AT VARIOUS TEMPERATURES AND EXPOSURE TIMES EXPRESSED AS A PERCENTAGE OF ROOM TEMPERATURE VALUES

Temp. °F	Exposure Time, hr	Yield Stress			Ultimate Stress		Modulus of Elasticity		Ultimate Stress, 3/16 in.	
		Tensile	Compressive	Bearing	Tensile	Bearing	Tensile	Compressive	Tensile	Shear
78		70,150 psi	81,900 psi	101,700 psi	76,930 psi	123,500 psi	10.6 x 10^6 psi	10.3 x 10^6 psi	83,050 psi	45,600 psi
212	0.5	88.1	88.6	89.4	89.5	88.6	90.5	91.2	92.8	96.2
	2	92.7	88.8	92.0	92.9	90.7			96.9	96.3
	10	93.6	89.5	90.6	94.3	91.0			96.9	97.6
	100	97.2	92.2	91.0	97.6	90.2			97.5	97.5
	1000	82.7	76.8	78.0	81.2	76.8			83.0	85.2
300	0.5	81.4	79.5	79.5	80.3	81.3	91.5	84.5	81.8	88.0
	2	80.5	80.0	80.2	80.7	80.1			82.1	87.3
	10	81.9	78.0	77.7	80.2	76.7			80.2	86.9
	100	62.0	57.2	60.7	59.7	59.7			59.5	62.3
	1000	46.1	38.2	42.6	47.7	43.0			46.8	48.9
400	0.5	51.9	49.0	54.2	54.7	51.8	83.0	77.7	55.0	58.4
	2	47.4	41.4	43.6	47.2	42.4			44.7	46.7
	10	35.6	32.9	37.2	35.2	35.6			35.4	39.7
	100	21.8	29.2	24.3	23.7	23.6			23.7	28.5
	1000	18.2	16.9	18.2	20.7	22.5			17.9	28.3
500	0.5	24.8	22.6	24.8	23.1	23.7	83.0	58.2	26.3	27.0
	2	21.2	21.1	23.3	20.6	22.6			22.2	22.6
	10	16.0	15.7	17.8	15.4	17.7			17.9	19.7
	100	13.4	13.0	14.6	13.4	15.6			15.8	19.1
	1000	12.7	12.2	13.7	13.7	15.9			14.2	18.6
600	0.5	11.4	11.0	12.4	11.8	12.7	68.8	49.5	14.7	14.9
	2	10.8	10.5	11.9	11.7	12.2			12.6	14.8
	10	10.5	9.9	10.0	11.4	11.3			11.9	15.4
	100	9.8	9.7	9.1	10.7	11.3			12.1	16.6
	1000	10.5	8.9	9.2	11.5	12.1			10.1	16.4

FIGURE 4.24 YIELD STRENGTH OF WROUGHT ALUMINUM ALLOYS AT ELEVATED TEMPERATURES AFTER 100 HOURS AT TEMPERATURE

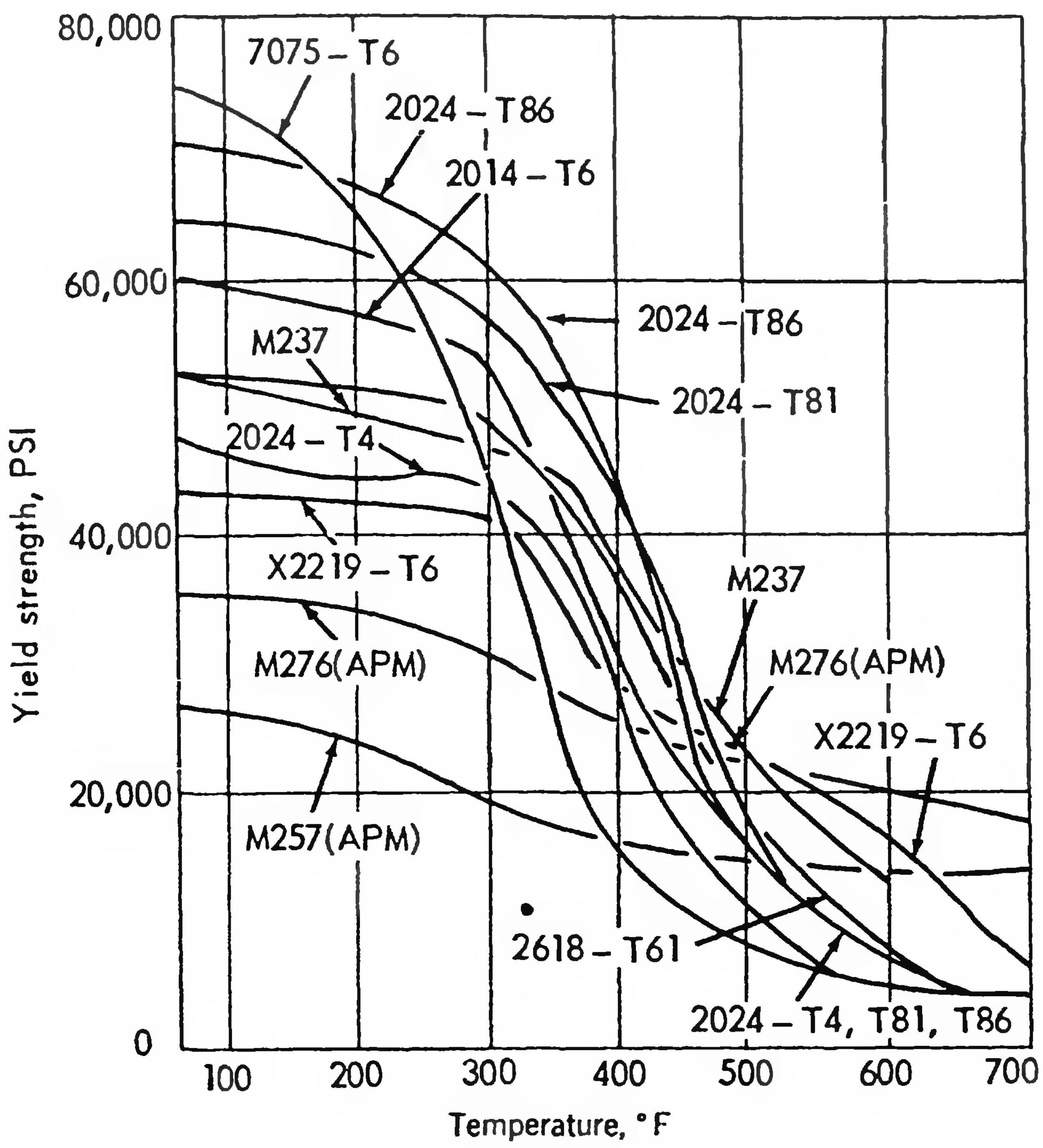


FIGURE 4.25 STRESS FOR CREEP AND RUPTURE FOR 2024 AND 2014 ALUMINUM ALLOYS

		2024 – T4	2014 – T6
300°F – Rupture in	1 hr	---	57,000
	1000 hr	40,000	40,000
Creep – 1.0 percent in	1 hr	46,000	54,000
	1000 hr	39,000	40,000
400°F – Rupture in	100 hr	26,000	25,000
	1000 hr	18,000	14,000
Creep – 1.0 percent in	1 hr	---	35,000
	1000 hr	15,000	11,000
600°F – Rupture in	10 hr	7,000	5,000
	1000 hr	2,700	2,500
Creep – 1.0 percent in	1 hr	---	5,700
	100 hr	3,600	2,800

FIGURE 4.26 TENSILE PROPERTIES OF NONHEAT-TREATABLE WROUGHT ALUMINUM ALLOYS AT LOW TEMPERATURES

Commercial Alloy & Temper	ASTM Alloy	+75°F				-18°F	
		Tensile Strength (psi)	Yield Strength* (psi)	Elong. in 2 In. (%)	Reduction in Area (%)	Tensile Strength (psi)	Yield Strength* (psi)
1160-O	996A	10,100	4,600	50.0	90	10,800	4,400
-H18		17,800	16,000	19.0	78	18,600	16,800
1100-0	990A	12,800	5,400	42.5	83	13,400	5,300
-H12		16,100	14,400	24.0	76	16,700	14,400
-H16		19,200	18,000	20.8	79	20,100	18,100
-H18		23,400	21,400	16.8	66	24,200	22,000
3003-0	M1A	15,600	5,900	41.6	76	16,600	6,100
-H12		19,900	18,300	24.0	76	21,200	18,800
-H14		23,100	21,500	14.4	54	24,000	21,900
-H18		29,600	26,700	12.2	50	31,000	27,400
3004-0	MG11A	27,800	10,200	25.8	64	28,600	10,400
-H34		35,400	28,600	15.5	54	36,700	28,900
-H38		42,000	36,700	14.0	45	42,800	36,800
5050-0	G1A	21,500	7,000	34.3	77	22,500	7,600
-H34		31,000	25,500	18.2	62	31,800	25,400
-H38		35,700	31,400	15.1	50	36,200	31,400
5052-0	GR20A	28,900	13,400	33.3	71	29,100	13,400
-H32		32,200	25,800	22.1	70	34,200	26,400
-H34		38,500	31,200	17.4	58	38,800	30,600
-H38		43,700	37,300	15.1	48	44,100	37,200
5154-0	GR40A	35,200	17,100	28.8	66	35,400	16,600
-H32		41,900	31,800	19.0	61	43,000	31,900
-H34		43,800	34,600	17.0	55	44,000	34,600
-H38		50,400	42,100	14.2	45	51,000	42,300
5056-0	—	44,900	24,700	31.2	57	44,100	23,200
-H38		57,000	42,400	17.8	44	57,400	43,400

* Offset = 0.2 percent.

FIGURE 4.26 TENSILE PROPERTIES OF NONHEAT-TREATABLE WROUGHT ALUMINUM ALLOYS AT LOW TEMPERATURES

		-112°F				-320°F			
Elong. in 2 In. (%)	Reduction of Area (%)	Tensile Strength (psi)	Yield Strength (psi)	Elong. in 2 In. (%)	Reduction of area (%)	Tensile Strength (psi)	Yield Strength (psi)	Elong. in 2 In. (%)	Reduction of Area (%)
51.0	90	12,200	4,800	53.0	90	22,200	5,500	60.0	86
20.5	79	19,600	17,400	24.5	81	28,300	19,900	43.0	77
44.0	82	14,800	6,800	45.8	82	24,800	6,400	55.0	78
23.2	76	18,000	15,000	27.0	77	27,400	16,600	45.8	75
21.5	81	21,200	18,600	24.0	81	30,900	21,200	38.0	76
16.4	65	25,400	22,600	18.8	70	33,700	25,800	33.6	70
42.2	76	18,800	6,800	43.5	76	32,000	8,700	46.4	67
23.5	75	23,200	19,600	27.2	76	35,600	22,900	40.0	69
15.0	58	25,300	22,300	18.5	59	36,600	25,900	32.5	56
11.5	51	32,400	28,800	13.8	55	42,400	32,700	27.5	54
27.8	66	30,500	10,600	31.5	66	45,300	13,000	39.2	58
16.5	55	38,800	29,200	19.5	56	52,500	34,100	26.3	53
14.9	48	45,000	38,000	16.8	49	58,600	44,400	22.6	46
33.8	78	23,800	8,400	38.0	78	37,100	9,500	45.5	70
18.5	64	33,600	26,300	21.5	68	46,700	31,000	29.8	63
15.0	55	37,900	32,200	17.5	58	50,200	38,300	26.3	53
35.0	74	30,500	12,700	39.5	75	45,300	15,600	50.3	67
21.8	73	36,000	27,000	25.1	73	50,800	30,600	35.1	64
18.8	62	40,700	31,800	21.0	60	55,400	37,100	29.7	56
16.5	54	46,000	38,000	19.2	55	60,900	44,500	26.3	50
31.5	72	36,500	17,200	35.0	73	51,200	19,600	41.6	60
22.0	68	44,300	32,600	25.3	68	62,300	37,400	34.0	53
19.8	62	45,300	35,400	20.5	64	55,800	39,800	23.0	58
16.9	55	52,200	43,800	19.8	56	67,400	49,900	24.4	48
34.9	65	43,900	23,300	36.6	67	61,300	26,900	46.9	56
18.7	46	58,100	44,500	21.3	56	75,900	50,200	28.0	44

FIGURE 4.27 TENSILE PROPERTIES OF HEAT-TREATABLE WROUGHT ALUMINUM ALLOYS AT LOW TEMPERATURES

		75°F				-18°F		
Commercial Alloy & Temper	ASTM Alloy	Tensile Strength (psi)	Yield Strength* (psi)	Elong. in 2 in. (%)	Reduction in Area (%)	Tensile Strength (psi)	Yield Strength* (psi)	Elong. in 2 in. (%)
2011-T3	CP60A	58,100	47,700	17.4	42	59,300	48,200	16.8
-T8		57,000	43,800	14.4	37	59,000	44,300	14.0
2014-T0	CS41A	26,000	9,900	26.5	45	26,400	9,400	27.2
-T4		67,200	44,500	20.2	28	70,700	46,000	21.0
-T6		70,600	63,600	10.4	24	72,800	65,200	10.6
2018-T61	CN42C	63,300	51,200	10.9	21	64,900	51,800	11.8
2218-T61	CN42D	59,200	43,400	14.6	24	60,500	44,200	14.8
2024-0	CG42A	30,300	11,000	22.7	40	31,200	11,400	22.7
-T4		76,000	56,200	15.4	22	77,100	57,300	15.8
-T36		71,600	54,000	14.0	22	73,200	54,500	17.3
-T6		72,600	58,100	14.5	26	72,800	58,300	12.7
4032-T6	SG121A	56,800	47,300	9.5	18	58,000	46,000	8.8
6151-T6	SG11A	45,600	41,900	15.9	44	48,100	44,100	15.2
6053-0	GS11B	15,500	7,000	39.8	72	16,500	6,800	42.2
-T4		36,300	22,600	27.5	54	39,900	24,100	27.5
-T6		39,000	32,000	20.8	51	40,300	32,700	21.2
6061-0	GS11A	17,700	6,800	34.8	73	18,500	7,100	36.4
-T4		40,300	21,800	30.5	57	41,700	22,500	31.5
-T6		45,100	38,800	20.6	53	47,100	39,300	20.2
6062-0	—	13,800	6,100	35.5	81	14,100	6,300	36.0
-T4		37,000	22,800	26.7	60	38,500	23,200	27.5
-T6		44,900	42,000	18.2	59	46,400	43,400	19.0
6063-0	GS10A	12,900	5,600	42.8	80	14,200	6,200	43.0
-T42		25,100	13,400	32.2	77	27,600	14,900	33.0
-T5		27,100	21,700	21.5	75	28,400	22,800	22.0
-T6		35,200	30,800	15.5	36	36,500	31,500	16.0
7075-0	ZG62A	34,500	15,600	18.8	40	35,400	15,400	19.5
-T6		88,500	79,700	12.0	21	92,400	83,900	10.7

* Offset = 0.2 percent.

FIGURE 4.27 TENSILE PROPERTIES OF HEAT-TREATABLE WROUGHT ALUMINUM ALLOYS AT LOW TEMPERATURES

	-112°F				-320°F			
Reduction of Area (%)	Tensile Strength (psi)	Yield Strength* (psi)	Elong. in 2 in. (%)	Reduction of Area (%)	Tensile Strength (psi)	Yield Strength* (psi)	Elong. in 2 in. (%)	Reduction of Area (%)
42	59,800	49,600	17.6	43	76,000	58,200	24.8	34
36	61,100	45,900	14.7	38	72,600	52,000	14.9	36
48	26,900	10,100	29.2	50	38,900	11,500	35.5	47
28	71,600	47,900	20.6	26	86,200	60,600	19.6	20
22	74,400	66,600	11.4	25	86,000	75,200	11.3	19
18	67,000	52,400	13.0	21	75,400	57,200	13.6	18
26	61,600	44,800	17.1	26	72,600	52,200	19.2	26
42	32,300	12,100	25.3	44	45,400	14,800	30.6	40
22	78,600	59,800	16.4	22	96,200	74,600	17.2	19
33	74,500	56,000	18.0	21	88,200	66,100	17.6	19
22	74,500	60,100	13.3	22	87,400	70,000	14.0	20
17	59,400	45,400	9.6	16	68,200	49,000	11.3	17
40	50,100	45,200	15.7	41	59,000	48,900	18.4	39
72	18.600	7,800	43,0	72	31,600	8,700	50.0	63
50	42,600	24,800	28.0	48	54,000	29,400	32.2	36
50	42,500	34,200	22.1	51	53,300	38,400	27.6	47
73	20,000	7,600	40.8	74	33,200	9,200	49.2	67
56	44,100	23,200	32.5	54	57,900	29,400	36.6	41
52	49,200	41,000	21.2	52	60,200	45,500	25.6	46
81	15,700	6,800	41.5	82	26,800	7,800	49.0	76
60	40,800	24,400	28.5	55	50,300	29,000	30.0	43
55	49,200	45,400	19.5	54	58,400	49,300	23.0	52
80	15,700	7,300	45.0	79	26,500	7,700	45.5	72
75	29,500	15,700	35.5	76	39,200	16,700	42.5	72
79	30,000	22,800	22.8	80	37,600	25,300	26.5	80
36	38,600	32,600	17.0	38	47,700	35,800	21.0	40
42	37,200	16,200	21.8	40	49,700	19,200	23.8	36
17	94,900	86,200	10.4	15	108,900	96,500	8.8	11

FIGURE 4.28 TENSILE PROPERTIES AND HARDNESS OF MAGNESIUM AT LOW TEMPERATURES

Alloy	Condition	Temperature (°C)	Temperature (°F)	Modulus, 1000 psi	Tensile, 1000 psi	Elong.in 2 in., %	Red. of Area (%)	Tensile Yield, 1000 psi	Hardness
ZK60A-F	As extruded	RM	RM	6450	50.5	22.2	35.3	38.9	78[3]
Nom. 5.5 Zn	(Bar Stock)	-18	0	6500	53.2	19.2	38.6	45.5	81[3]
0.6 Zr		-46	-50	6550	54.4	18.5	33.8	45.7	80[3]
		-68	-90	6500	56.6	17.5	28.2	52.2	88[3]
ZK60A-T5	Extruded and aged	RM	RM	6500	50.5	22.0	46.4	43.2	80[3]
Nom. 5.5 Zn	48 hr. at 275°F	-18	0	6500	54.6	18.5	42.8	48.6	80[3]
0.6 Zr	(Bar Stock)	-46	-50	6400	57.4	17.0	32.0	51.0	80[3]
		-68	-90	6400	60.2	15.5	34.8	—	88[3]
FS1-F	As Extruded	RM	RM	6500	42.5	12.2	26.8	34.4	55[3]
Nom. 3 Al	(Bar Stock)	-18	0	6400	46.3	12.8	27.4	39.4	56[3]
1 Zn		-46	-50	6500	48.6	10.8	16.2	43.2	58[3]
		-68	-90	6550	49.6	14.2	23.8	45.8	62[3]
FS-1	As extruded	25	77	6360	40.1	16.5	36.5	29.9	104[4]
3.10 Al	(3/4" round)	-78	-108	6580	45.6	15.0	22.5	39.8	114[4]
1.05 Zn		-192	-314	7300	62.8	6.5	8.0	48.4	130[4]
.49 Mn									
ASTM #18 Ga.[1]	As Extruded	26	79	—	39.5	—	31.0	26.0	—
2.7 Al	(1" round)	-78	-108	—	45.5	—	10.0	35.5	—
1.0 Zn		-188	-306	—	59.5	—	7.0	46.0	—
0.3 Mn									
J[1]	As Extruded	RM	RM	6250	47.0	13.0	17.0	34.0	74[5]
5.8 Al	(1/2" square)	-78	-108	6800	50.0	12.0	16.5	41.0	81[5]
1.0 Zn		RM[2]	RM[2]	6400	46.0	14.5	32.5	33.0	74[5]
0.22 Mn									
0.06 Fe									

(1) Values picked from curves
(2) After exposure at -100 F
(3) Brinell, 500 kg load, 10mm ball
(4) Vickers pyramid
(5) Rockwell E

FIGURE 4.29 NOMINAL MECHANICAL PROPERTIES FOR COMMERCIAL TITANIUM

Commercial Designation*	Form	Condition	Yield Stress 0.2% Offset (psi)	Tensile Stress (psi)	Elong. (% in 2 in.)	Red. of Area (%)	Hardness	
							Rockwell	Brinell
Commercial Titanium								
Ti-55 A	Sheet and strip	Annealed	48,000	65,000	26.5	...	R_b80	...
Ti-75 A	Sheet and strip	Annealed	75,000	88,000	21	...	R_b90	...
	Plate	Annealed	68,000	85,000	21.5	...	...	219
	Wire	Annealed	72,000	83,000	22.5	47.5	...	...
		Cold drawn, full hard	125,000	145,000	11.5	37.5	...	...
	Forgings, hot-rolled bars	Annealed	60,000	80,000	25	...	...	190
Ti-100 A	Sheet and strip	Annealed	95,000	110,000	17.5	...	R_b98	...
	Plate	Annealed	100,000	110,000	18.5	...	...	270
	Wire	Annealed	88,000	108,000	22.5	47.5	..	...
		Cold drawn, full hard	160,000	190,000	12.5	25	...	...
	Forgings, hot-rolled bars	Annealed	88,000	102,000	20	...	...	252
MST Grade III	Sheet	Annealed	90,000	80,000	20	50	R_a60	...
		Cold worked, 50%	110,000	125,000	12	30	R_a64	...
	Forgings	As forged	72,000	80,000	25	55	R_a62	...
MST Grade IV	Sheet, 0.040 in.	Annealed 1 hr at 1300 F	85,000	100,000	18	15	R_a61	...
		Cold worked, 37%	120,000	130,000	6	14	R_a65	...
	Forgings	Hot forged, 80% reduction	75,000	80,000	18	50	R_a61	...
RC-55	Sheet, bar, plate	Annealed	65,000	75,000	25	55	R_a50-54	...
	Forgings	Annealed	65,000	75,000	15	30	R_a50-54	...
RC-70	Sheet	Annealed	80,000	90,000	20	50	R_a54-58	...
		½ hard	105,000	120,000	12	35	...	...
	Forgings	As forged	80,000	90,000	15	30	R_a54-58	...

FIGURE 4.29 NOMINAL MECHANICAL PROPERTIES FOR COMMERICAL TITANIUM (cont.)

Commercial Designation*	Form	Condition	Yield Stress 0.2% Offset (psi)	Tensile Stress (psi)	Elong. (% in 2 in.)	Red. of Area (%)	Hardness	
							Rockwell	Brinell
Titanium Alloys								
Ti-150 A	Plate	Annealed	120,000 min	152,000	12 min	...	...	341
	Forgings, hot rolled bars	Annealed	120,000 min	150,000	15 min	...	...	341
Ti-150 B	Sheet and strip	Annealed	135,000 min	160,000	10	...	R_c35	...
	Plate	Annealed	135,000 min	160,000	10	...	...	322
Ti-170 A	Sheet	Annealed	140,000	180,000	30	...	...	364
Ti-175 A	Plate	Annealed	140,000 min	172,000	8 min	...	...	379
	Forgings, hot rolled bars	Annealed	140,000 min	170,000	10 min	...	...	379
MST(3 Al-5 Cr) L-2748	Forgings	Hot forged, 80% reduction	153,000	165,000	8	51	R_a71	...
		Furnace cooled	145,000	155,000	13.5	40	R_a73	...
	@ 600 °F	Forged	92,000	117,000	22	70		
MST(2.5 Fe-2.5V) L-2841	Sheet, 0.40 in.	Annealed 1 hr at 1300 F	125,000	135,000	10	...	R_a65	...
		Cold worked, 37%	170,000	175,000	2	...	R_a68	...
	Forgings	Hot forged, 80% reduction	105,000	130,000	12	35	R_a65	...
MST(2 Al-2 Fe) L-2852	Sheet, 0.040 in.	Annealed 1 hr at 1300 F	...	140,000	14	...	R_a68	...
		Cold worked, 37%	...	180,000	6	...	R_a70	...
	Forgings	Hot forged, 80%	135,000	145,000	12	35	R_a68	...
RC-130 A	Sheet	Annealed	130,000	150,000	25	35	R_c33-36	...
RC-130 B	Bar	Annealed	140,000	150,000	20	40	...	...
	Forgings	As forged	130,000	150,000	15	30	R_c33-36	...

* RC—Rem-Cru Titanium, Inc.
MST—Mallory Sharon Titanium Corp.
Ti—Titanium Metal Corp.

FIGURE 4.30 PHYSICAL PROPERTIES OF SAE 4130 ALLOY STEEL FOR VARIOUS TEMPERATURES AND EXPOSURE TIMES EXPRESSED AS A PERCENTAGE OF ROOM TEMPERATURE VALUES

Temp. °F	Exposure Time, hr	Yield Stress			Ultimate Stress		Modulus of Elasticity		Ultimate Stress, 3/16 in.	
		Tensile	Compres-sive	Bearing	Tensile	Bearing	Tensile	Compressive	Tensile	Shear
78		97,050 psi	102,900 psi	133,100 psi	111,100 psi	169,000 psi	29.75 x 10	30.0 x 10	113,900 psi	73,200 psi
400	0.5	82.7	84.7	90.4	90.2	92.6	98.2	97.5	93.7	90.5
	2	83.7	89.1	91.9	90.9	91.2			93.2	91.7
	10	82.3	91.8	90.6	90.8	90.7			93.0	91.7
	100	83.8	89.4	93.7	89.7	91.6			93.3	91.5
600	0.5	80.6	83.4	93.5	92.0	94.7	95.8	96.4	93.0	94.6
	2	80.1	81.0	91.7	91.5	95.0			94.4	93.3
	10	79.9	84.4	90.2	90.7	94.5			95.7	93.5
	100	79.7	78.7	91.7	90.9	93.8			94.2	93.5
800	0.5	73.6	70.3	79.9	79.1	78.8	108.5	86.7	83.7	82.8
	2	68.6	70.7	81.4	79.3	78.7			81.4	82.5
	10	74.7	70.8	80.6	81.8	78.2			83.4	81.8
	100	71.1	71.6	79.9	81.7	78.3			81.4	81.5
1000	0.5	55.6	55.6	70.1	55.8	59.8	58.4	72.3	63.2	61.7
	2	52.7	57.3	65.7	57.0	59.4			62.7	61.4
	10	57.7	59.4	65.9	58.0	58.5			64.2	61.0
	100	52.9	57.7	62.2	56.3	57.3			62.2	61.8
1200	0.5	24.0		37.7	39.2	37.1	34.6		40.5	37.7
	2	24.0		38.9	36.3	37.7			41.3	37.7
	10	25.7		39.8	37.2	36.4			40.6	36.5
	100	23.5		35.3	29.0	30.8			34.5	32.5

FIGURE 4.31 EFFECT OF TEMPERATURE AND EXPOSURE TIME ON TENSILE, COMPRESSIVE, AND BEARING YIELD STRESSES OF SAE 4130 ALLOY STEEL

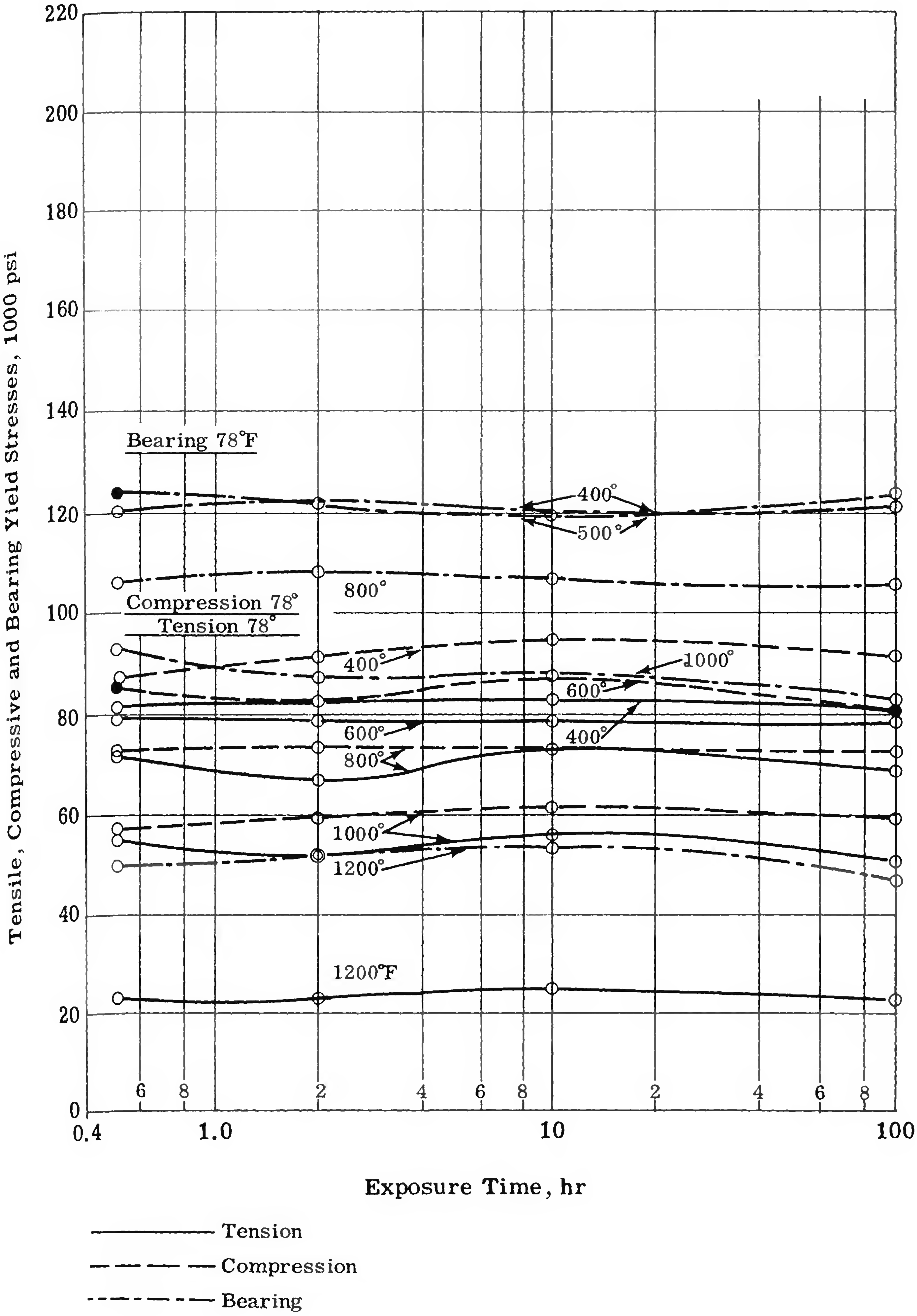


FIGURE 4.32 PHYSICAL PROPERTIES OF ANNEALED STAINLESS STEEL FOR VARIOUS TEMPERATURES AND EXPOSURE TIMES EXPRESSED AS A PERCENTAGE OF ROOM TEMPERATURE VALUES

Temp. °F	Exposure Time, hr	Yield Stress			Ultimate Stress		Modulus of Elasticity		Ultimate Stress, 3/16 in.	
		Tensile	Compressive	Bearing	Tensile	Bearing	Tensile	Compressive	Tensile	Shear
78		45,000 psi	45,730 psi	73,100 psi	89,440 psi	167,750 psi	23.4×10^6	26.0×10^6	86,900 psi	81,980 psi
400	0.5	73.3	78.3	85.4	76.7	66.3	108.2	95.8	79.2	62.2
	2	69.6	79.8	76.2	75.5	65.6			76.4	62.2
	10	71.7	80.9	78.2	76.5	66.0			77.7	62.1
	100	70.0	81.4	75.0	75.2	65.4			80.0	61.2
600	0.5	68.2	75.9	78.1	75.8	65.2	114.2	88.2	77.0	61.0
	2	68.8	74.3	73.7	75.8	63.4			77.5	59.3
	10	68.0	69.3	74.4	73.7	64.8			74.9	59.3
	100	65.8	71.4	78.7	74.5	65.0			75.5	60.5
800	0.5	65.4	67.7	75.9	72.5	62.1	115.0	88.5	74.0	58.0
	2	61.4	67.2	72.6	70.5	62.8			72.8	58.6
	10	63.3	66.7	72.7	73.4	66.6			74.8	59.2
	100	63.8	67.4	68.8	72.8	59.8			73.2	58.7
1000	0.5	56.4	62.8	63.2	66.8	55.7	84.9	92.0	67.6	51.0
	2	53.8	62.8	68.2	68.5	56.2			68.6	53.5
	10	55.1	60.6	65.6	70.7	55.7			69.2	53.6
	100	54.3	62.8	61.5	69.4	56.3			67.5	52.8
1200	0.5	51.8		60.2	60.9	48.4	89.3		58.2	46.9
	2	50.6		60.2	60.3	48.2			58.5	55.0
	10	52.2		58.3	60.9	47.8			55.6	53.8
	100	49.3		58.2	58.2	46.2			54.9	49.7

FIGURE 4.33 GALVANIC SERIES IN SEA WATER

	Corroded End (anodic, or least noble)
GROUP 1	MAGNESIUM MAGNESIUM ALLOYS
2	ZINC GALVANIZED STEEL OR GALVANIZED WROUGHT IRON ALUMINUM 5052 (52S), 3004 (4S), 3003 (3S), 1100 (2S), 6061-T (61S-T), 6053-T (53S-T), 2024-T (24ST), ALCLAD 356, 13, 4043 (43S) CADMIUM
3	ALUMINUM 2117-T (A17S-T), 2017-T (17S-T), 7075-T (75S-T), 2024-T (24S-T) IN THIS ORDER
4	MILD STEEL WROUGHT IRON CAST IRON
5	NI-RESIST 13% CHROMIUM STAINLESS STEEL TYPE 410 (ACTIVE) 17% CHROMIUM STAINLESS STEEL TYPE 430 (ACTIVE) HASTELLOY C
6	50-50 LEAD TIN SOLDER 18-8 STAINLESS STEEL TYPE 304 (ACTIVE) 18-8-3 STAINLESS STEEL TYPE 316 (ACTIVE) LEAD TIN
7	MUNTZ METAL MANGANESE BRONZE NAVAL BRASS MOLYBDENUM NICKEL (ACTIVE) INCONEL (ACTIVE) HASTELLOY A HASTELLOY B
8	YELLOW BRASS ADMIRALTY BRASS ALUMINUM BRONZE RED BRASS COPPER SILICON BRONZE 90-10 COPPER NICKEL 70-30 COPPER NICKEL COMP. G-BRONZE COMP. M-BRONZE
9	NICKEL (PASSIVE) INCONEL (PASSIVE) MONEL 13% CHROMIUM STAINLESS STEEL TYPE 410 (PASSIVE) 17% CHROMIUM STAINLESS STEEL TYPE 430 (PASSIVE) 18-8 STAINLESS STEEL TYPE 304 (PASSIVE) 18-8-3 STAINLESS STEEL TYPE 316 (PASSIVE) TITANIUM
	Protected End (cathodic, or most noble)

FIGURE 4.34 SOUND IN SOLIDS

The velocity of sound in solids is determined by the shape and size of the bounded medium as compared with the wavelength of the excitation. For rods or square bars with unconstrained sides, the velocity of propagation varies with the ratio of thickness to wavelength, being, for a wavelength in diameter, about 0.65 times the zero-diameter-to-wavelength ratio.

Material	Velocity	
	cm/sec x 10^5	ft/sec
Aluminum	5.24	17180
Antimony	3.40	11150
Beryllium	16.53	42000
Bismuth	1.79	5870
Brass	3.42	11220
Cadmium	2.40	7870
Constantan	4.30	14100
Copper	3.58	11740
German Silver	3.58	11740
Gold	2.03	6660
Iridium	4.79	15710
Iron	5.17	16950
Lead	1.25	4100
Magnesium	4.90	16060
Manganese	3.83	12560
Nickel	4.76	15610
Platinum	2.80	9180
Silver	2.64	8655
Steel	5.05	16560
Tantalum	3.35	10980
Tin	2.73	8950
Tungsten	4.31	14140
Zinc	3.81	12480
Cork	0.50	1640
Crystals		
Quartz X-cut	5.44	17840
Ammonium di-hydrogen phosphate (NH H PO)		
45° Z-cut	3.28	10760
Rochelle salt (sodium potassium tartrate)		
Crystals, (cont.)		
KNaC H O . 4H O		
45° Y-cut	2.47	8100
45° X-cut	2.47	8100
Calcium fluoride (CaF fluorite)		
X-cut	6.74	22100
Sodium chloride (NaCl, rock salt)		
X-cut	4.51	14780
Sodium bromide (NaBr)		
X-cut	2.79	9145
Potassium chloride (KCl, sylvite)		
X-cut	4.14	13570
Potassium bromide (KBr)		
X-cut	3.38	11080
Glasses		
Heavy flint	3.49	11440
Extra-light flint	4.55	14920
Crown	5.30	17380
Heaviest crown	4.71	15440
Quartz	5.37	17600
Granite	3.95	12950
Ivory	3.01	9865
Marble	3.81	12480
Slate	4.51	14790
Wood		
Elm	1.01	3310
Oak	4.10	13440

FIGURE 4.35 THERMAL LIMITS OF NON-METALS

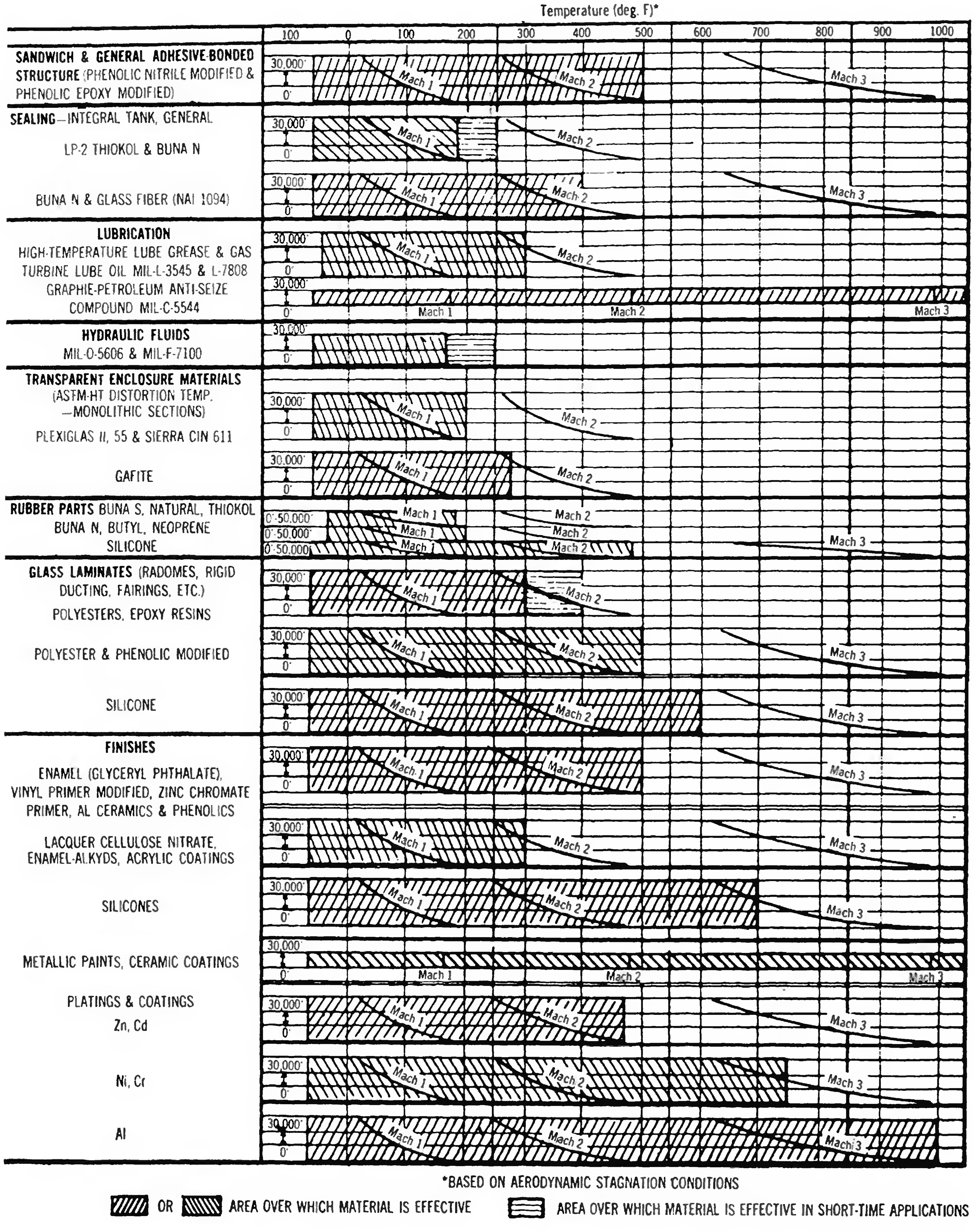


FIGURE 4.35A TEMPERATURE LIMITS FOR VARIOUS MATERIALS, °F

	°F
Synthamica melts	2550
Electrical porcelain - firing temperature	2400
Glaze for porcelain - firing temperature	2250
Synthamica - maximum heat resistance	2200
Copper melts	1981
Natural phlogopite mica - maximum heat resistance	1800
Silver melts	1762
Aluminum melts	1220
Silver solders melt	1165-1450
Aluminum alloy melting points	850-1225
Zinc melts	786
Mycalex 400 - sustained service	700
Magnesium alloy melting points	650-1200
Lead melts	621
Cadmium melts	610
Silicone - glass heat distortion	575
Polytetrafluorethylene - sustained service, no load	500
Silicone - glass sustained service	480
Tin melts	450
Silicone rubber - sustained service	425
Cold - molded plastic (organic) heat distortion	400
Polyester - glass heat distortion	400
Cellulose - filled melamine heat distortion	400
RDX melts	392
Mercury boils	357
Tetryl melts	320
Epoxy - glass cloth - maximum temperature	315
Silicone elastomer - sustained service	300-500
Nylon (polyamide) heat distortion (66psi)	300-360
Polytetrafluoroethylene heat distortion (66 psi)	270
Melamine - formaldehyde (filled) heat distortion	266-400
Phenol - formaldehyde (mica) heat distortion	260-350
Hard-rubber (mineral-filled) heat distortion	260
Paper/Phenolic laminate - sustained service	212-250
Styrene elastromer - upper limit	212
Epoxy - maximum recommended use	212
Polystyrene heat distortion	152-210
Methyl methacrylate heat distortion	150-210
Vinyl chloride heat distortion	140-185
Hard rubber (no filler) heat distortion	140
Polyethylene heat distortion (66psi)	107
Lower limit for vinyl chloride elastomer	-38
Silicone elastomer loses flexibility	-60
Lower limit for polytetrafluoroethylene	-90
Dry ice (CO_2) sublimes	-109
Mycalex glass-bonded mica undamaged	-110

FIGURE 4.36 MECHANICAL PROPERTIES OF REPRESENTATIVE PLASTICS

	Tensile Strength, psi	Compressive Strength, psi	Flexural Strength, psi	Impact Strength Izod, ft lbs/in. notch	Specific Gravity	Heat Distortion (264 psi), deg F	Modulus of Elasticity, psi x 10^6	Coefficient of Thermal Expansion, per C x 10^{-5}
UNCOMPOUNDED PLASTICS								
Epoxy	12,000	17,000	20,000	0.5	1.2	210	4.5	—
Nylon	10,500	—	13,800	1.0	1.14	360	2.0 - 4.0	10 - 15
Melamine	9,000	40,000	13,000	0.4	1.5	—	—	—
Polyvinyl chloride (rigid)	8,000	10,000	13,000	0.7	1.4	165	5.6	5 - 6
Modified styrene copolymers	8,000	—	15,000	0.5	1.05	190	4 - 6	3.5 - 12
Phenolic	7,500	15,000	15,000	0.3	1.3	—	7 - 10	2.5 - 6
Urea	7,500	30,000	14,000	0.3	1.5	—	15	2.5 - 3.0
Vinly chloride acetate (rigid)	7,000	10,000	13,000	0.6	1.4	145	3.5	7 - 17
Methyl methacrylate (acrylic)	7,000	12,000	13,000	0.5	1.2	170	4.5	9
Polystyrene	7,000	16,000	11,000	0.35	1.05	185	4 - 6	7
Polyester	6,000	20,000	12,000	0.3	1.3	—	3 - 6.5	5.5
Cellulose acetate	6,000	20,000	—	2.0	1.3	145	2.5 - 3.0	8 - 16
Styrene-rubber blends	5,000	7,000	9,000	8.0	1.05	175	1.8 - 4.0	6 - 13
Silicene	4,000	9,000	8,000	8.0	1.7	550	—	2.0
Alkyd	3,500	19,000	9,000	0.3	2.2	375	—	—
Polytetrafluoroethylene	1,800	—	—	3.0	2.2	270	0.5 - 0.6	10
Polyethylene (general purpose)	1,300	—	—	—	0.92	175	0.25 - 0.50	17
Polyethylene (high density)	3,200	—	—	2.5	0.93	250	—	—
GLASS FABRIC REINFORCED PLASTICS								
Polyester	40-50,000	30-60,000	50-63,000	19 - 35	1.6 - 2.0	300/400	1 - 2.8	
Epoxy	33-46,000	50-90,000	45-80,000	6 - 16	1.7 - 1.9	300/360	2.5 - 3.5	
Melamine	20-50,000	30-85,000	28-55,000	5 - 15	1.82 - 1.98	300	—	
Phenolic	11.5-40,000	42-60,000	20-40,000	3 - 16	1.5 - 2.1	290	1.0 - 2.0	
GLASS-FILLED PREMIX MOLDING COMPOUNDS								
Polyester	4-10,000	20-26,000	5-25,000	3 - 6	1.7 - 2.0	300	1.6 - 2.0	
Melamine	6-10,000	10-25,000	9-20,000	8 - 12	1.9 - 2.0	300	—	
Phenolic	7-10,000	17-26,000	18,000	12 - 50	1.75 - 1.95	350/450	3.3	
Polystyrene	10,500	14,500	12,000	2	1.3	—	1.28	

FIGURE 4.37 CHANGE OF MECHANICAL PROPERTIES OF PLASTICS WITH DECREASING TEMPERATURE

i - Increases with decreasing temperature

n - No change with decreasing temperature

d - Decreases with decreasing temperature

Material Group	Approximate Room Temp. Values and Behavior with Decreasing Temperature				
	Ultimate Tensile Strength, 1000 psi	Elonga-tion, %	Mod. of Elasticity, 10^6 psi	Work to Produce Failure, Ft lb/in.^{3}	Izod Impact, Ft lb/in. of notch
Thermosetting, laminated, glass fabric base*	30. i	1.5 i	2. n	25. i	10. i
Thermosetting, laminated paper base	20. i	1.5 d	1.5 i	20. d	1. d
Thermosetting, laminated cotton base	12. i	4. d	1. i	30. d	2. d
Thermosetting, molded, phenolics	5. i	1. d	1.5 i	2. d	2. d
Thermosetting, molded, miscellaneous	5. n	.4 d	2. i	2. d	.3 n
Thermosetting, cast, miscellaneous	6. i	1.5 d	.5 i	5. d	.3 n
Thermo plastic, cellulose acetates	4. i	12. d	.3 i	30. d	3. d
Thermo plastic, cellulose acet. butyrates	5. i	15. d	.3 i	60. d	3. d
Thermo plastic, cellulose propionate	6. i	13. d	.3 i	60. d	3. d
Thermo plastic, ethyl cellulose	5. i	6. d	.2 i	20. d	3. d
Thermo plastic, cellulose nitrate	9. i	15. d	.2 i	100. d	2.5 d
Thermo plastic, polystyrene	6. i	5. d	.4 i	20. d	.5 d
Thermo plastic, polymethyl methacrylate	10. i	6. d	.4 i	37. d	.4 n

* Stronger and stiffer laminates are available. Ex.: 91-LD phenolic resin-fiberglass laminate, 181-114 cloth. $F_{t_u} \sim 60$, $E \sim 4$.

FIGURE 4.38 EFFECTS OF TEMPERATURE ON PHYSICAL PROPERTIES OF REPRESENTATIVE PLASTICS

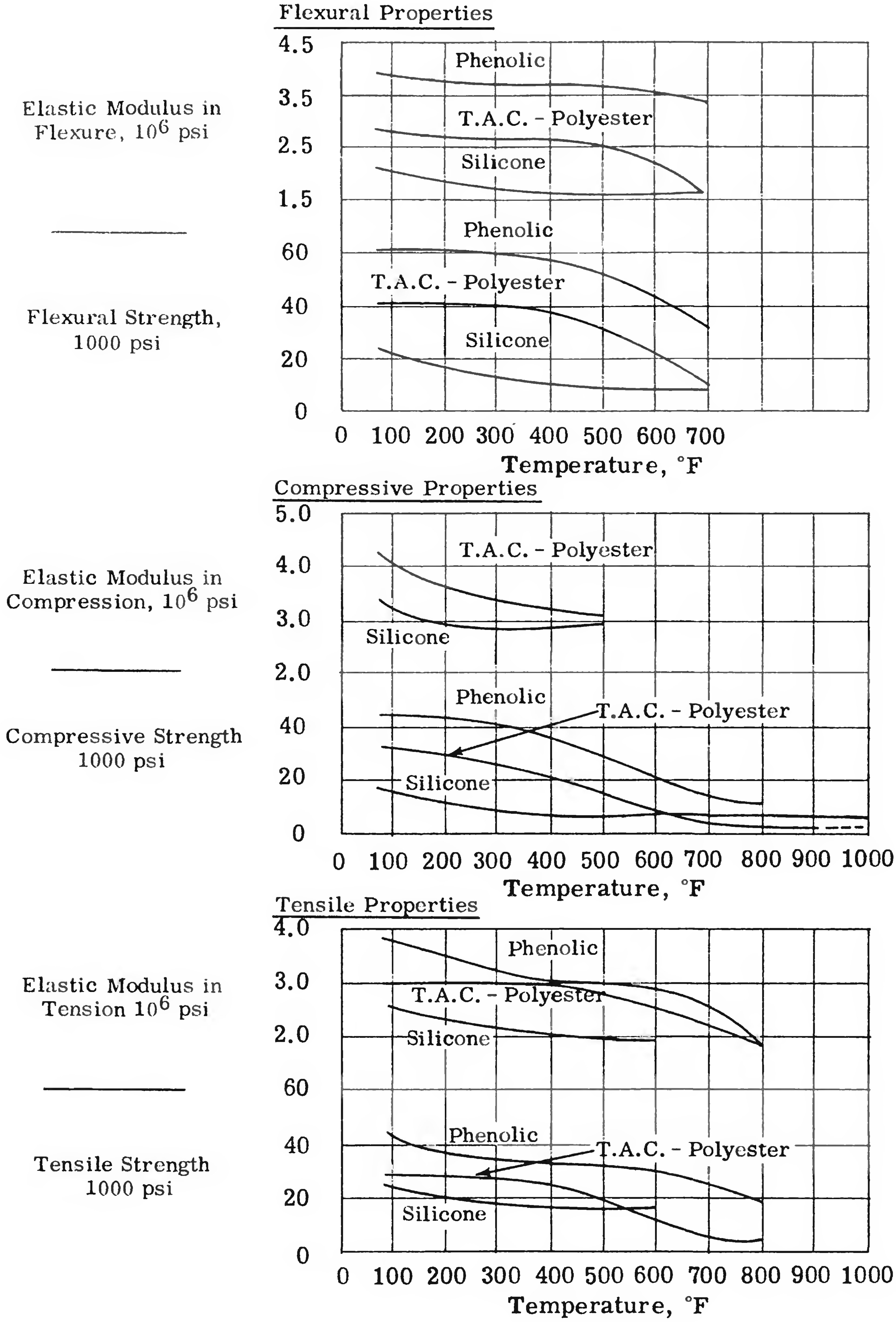
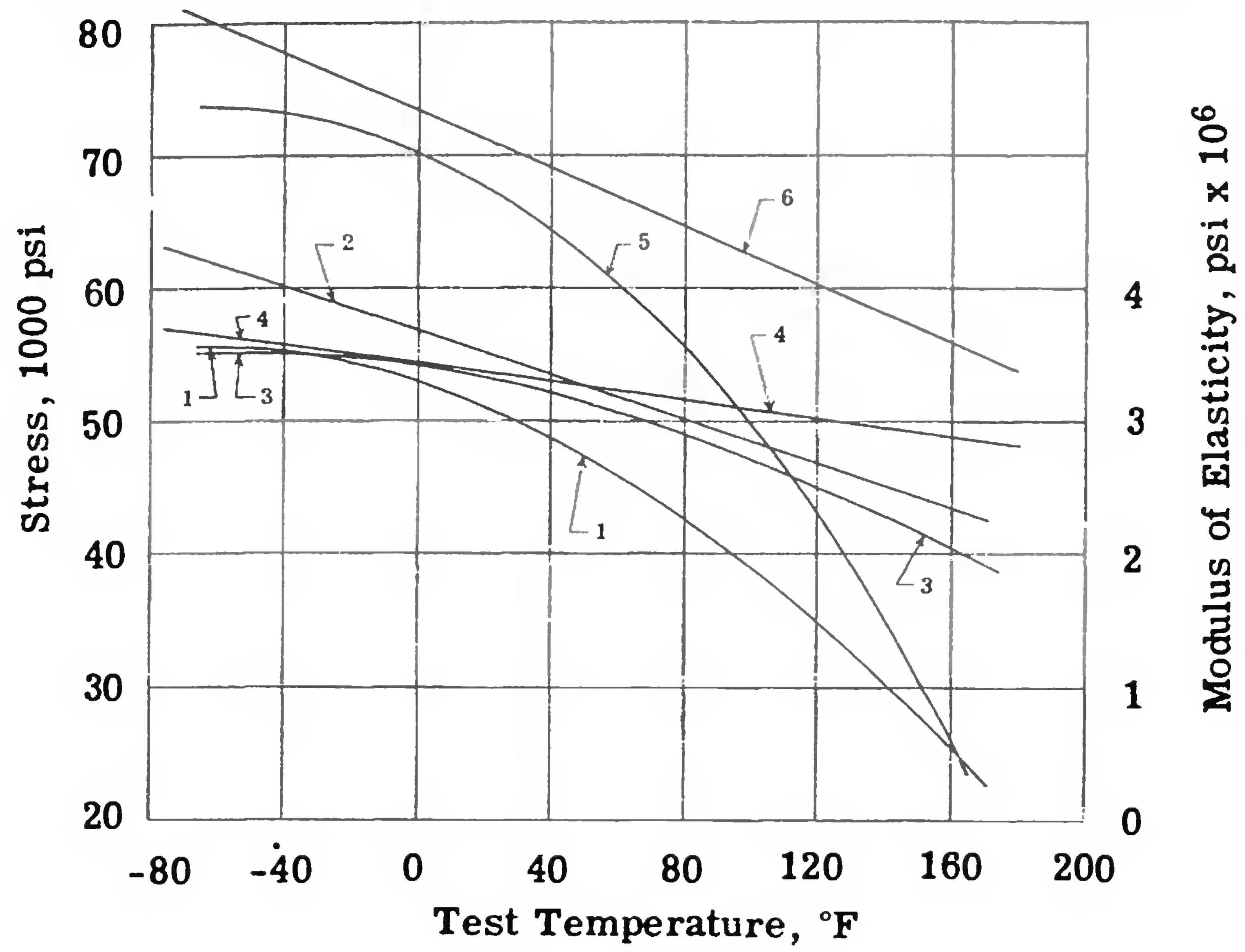


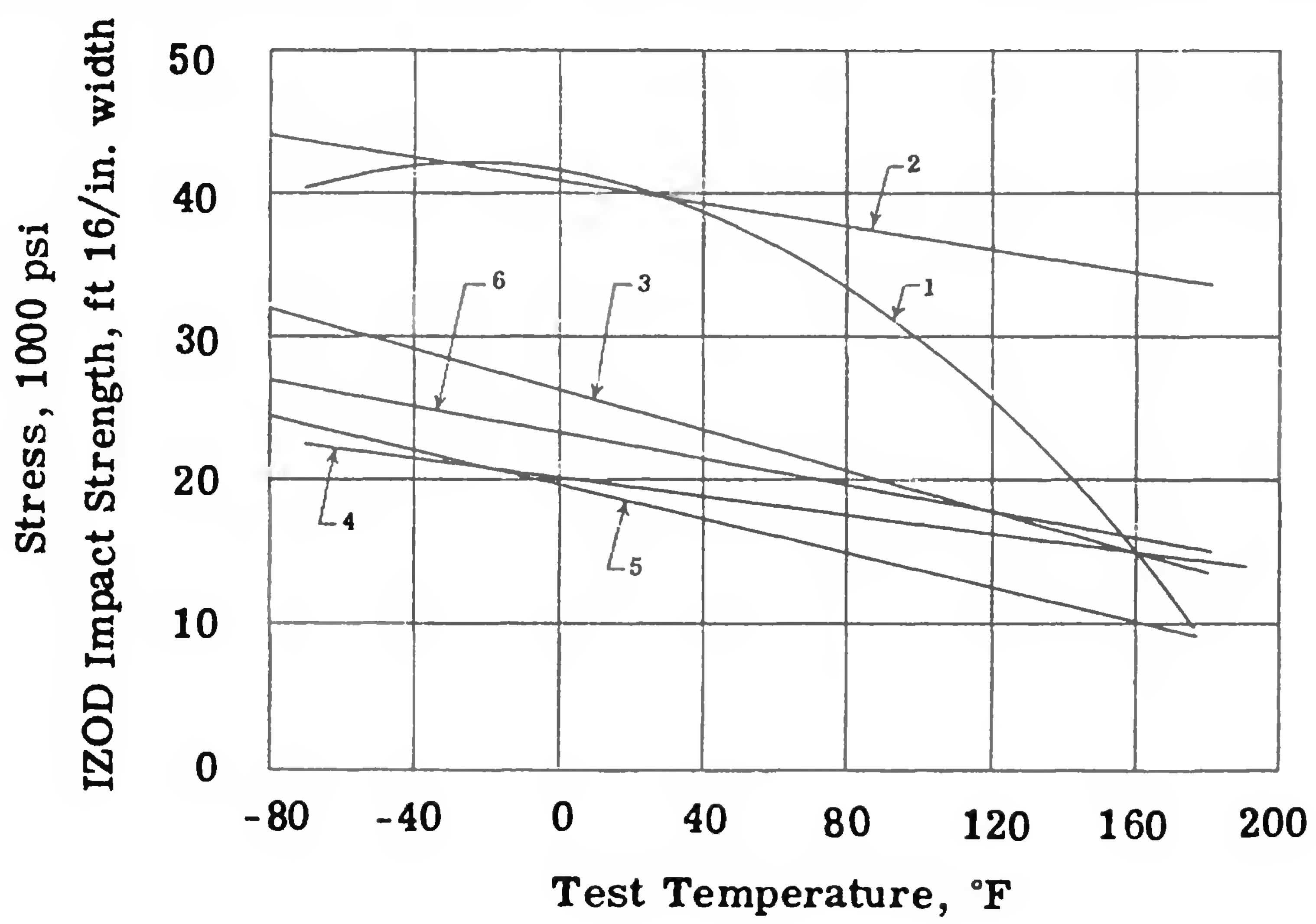
FIGURE 4.39 EFFECT OF TEST TEMPERATURE ON TENSILE AND FLEXURAL PROPERTIES OF PHENOLIC RESIN AND POLYESTER RESIN-FIBERGLASS LAMINATES



LEGEND

1. F_{t_u}, polyester resin.
2. F_{t_u}, phenolic resin.
3. E_{sec} at .1% offset, polyester resin.
4. E_{sec} at .1% offset, phenolic resin.
5. F_{b_u}, polyester resin.
6. F_{b_u}, phenolic resin.

FIGURE 4.40 EFFECT OF TEST TEMPERATURE ON COMPRESSIVE, SHEAR, AND IZOD IMPACT STRENGTH OF PHENOLIC RESIN- AND POLYESTER RESIN-FIBERGLASS LAMINATES



LEGEND

1. Edgewise compressive stress, polyester resin.
2. Edgewise compressive stress, phenolic resin.
3. Flatwise shear stress, polyester resin.
4. Flatwise shear stress, phenolic resin.
5. Izod impact strength, polyester resin.
6. Izod impact strength, phenolic resin.

FIGURE 4.41 PROPERTIES OF STRUCTURAL ADHESIVES

		Phenolic Elastomers	Vinyl Phenolics	Modified Epoxies: Room-Temperature Cured	Modified Epoxies: Heat Cured
Shear Strengths at Various Temperatures	Room temperature	3000-4200 psi	2500-5000 psi	2500-4200 psi	3000-5000 psi
	-65 F	3500-4500 psi	2000-3000 psi	350-2500 psi	1300-5000 psi
	180 F	1500-2800 psi	800-4000 psi	180-900 psi	2600-5000 psi
	250 F	500-2500 psi	100-1800 psi	—	800-3600 psi
	300 F	400-2200 psi	100-1200 psi	—	450-3200 psi
	350 F	300-1700 psi	100-500 psi	—	200-1200 psi
Physical Properties	Flexibility	Excellent	Fair	Poor	Poor
	Room temperature creep and dead load strength	Good	Excellent	Excellent	Excellent
	Elevated temperature creep and dead load strength	Good	Good to limitimg temperature	Poor	Good to limitimg temperature
	Peel strength	Excellent	Fair	Poor	Poor
Resistance to:	Water	Excellent	Excellent	Fair	Excellent
	100 per cent humidity	Excellent	Excellent	Fair	Excellent
	Salt spray	Excellent	Excellent	Poor	Excellent
	Oils	Excellent	Excellent	Excellent	Excellent
	Glycols	Excellent	Excellent	Good	Good
	Fuels	Excellent	Excellent	Excellent	Excellent
Curing Procedure	Cure temperature	300-400 F	250-350 F	70-90 F	200-350F
	Cure pressure	25-200 psi	50-200 psi	Contact	Contact
	Cure time	30-240 minutes	30-120 minutes	1-7 days	60-90 minutes

FIGURE 4.42 PHYSICAL PROPERTIES OF REFRACTORY MATERIALS

Material	Melting or Decomposition Temp. °F	*True Specific Gravity	**Apparent Specific Gravity	Linear Coefficient of Expansion °C x 10^{-6}	Thermal Conductivity Btu/hr/ft²/in/°F.	Specific Heat
Chromic Oxide	3614	5.21		7.0 - 12.0		
Alumina	3660	3.97	2.95	8.1	18	0.27
Silicon Carbide	3990	3.17	2.82	4.5	56	.19
Niafrax A			2.77	6.7	113	
Lt. Wt. Niafrax			2.30			
Boron Carbide	4440	2.51	2.51	4.5		
Zircon	4532	4.56	3.32	5.1	12	.132
Beryllia	4550	3.02		8.0	104	.50
Zirconia	4892	6.27	4.40	11.0	5	.168
Magnesia	5072	3.58	2.50	14.3	23	.187
Thoria	5522	9.69	7.34	9.4		.06
Titanium Carbide	5748	4.25				
Graphite	6332	2.25	1.60	1.5	600	.34

* True Specific Gravity is based on a solid mass.

** Apparent Specific Gravity accounts for the voids that exist in refractories.

FIGURE 4.43 TABLE OF DIELECTRIC CHARACTERISTICS

Dielectric material[1]	Dielectric constant (K)	Power factor					Dielectric strength (puncture voltage)[2]	Volume resistivity[3]
		60 cycles	1 kc	1 Mc	10 Mc	100 Mc		
Air (normal pressure)	1.0						19.8 - 22.8	10^{14}
AlSiMag A196	5.7 - 6.3	2.9		.0.21	0.15		240	
Aniline formaldehyde	3 - 5	1 - 6					400	
Asphalts	2.7 - 3.1		2.3				25 - 30	
Bakelite — See Phenol								
Beeswax	2.9 - 3.2							
Casein plastics[4]	6.1 - 6.4			5.2 - 6			165	
Castor oil	4.3 - 4.7			7			380	
Celluloid	4 - 16			5 - 10				
Cellulose acetate[5]	6 - 8	3 - 6	4 - 6	4 - 6	5.5		300 - 1000	4.5×10^{10}
Cellulose nitrate[6]	4 - 7			2.8 - 5			300 - 780	$2 - 30 \times 10^{10}$
Ceresin wax	2.5 - 2.6			0.12 - 0.21				
Cresol formaldehyde	6	10					400	
Dilcetone	3.57					0.33		
Ethyl cellulose	2 - 2.7	0.7	1.2	1.5			1500	10^{15}
Fiber	5 - 7.5			4.5 - 5			150 - 180	5×10^{9}
Formica MF-66	4.0 - 4.9		1.5	1.1			450	
Glass:								
Cobalt	7.3			0.7				
Common window	7.6 - 8			1.4			200 - 250	
Crown	6.2 - 7		1	1[3]			500	
Electrical	4 - 5			0.5			2000	8×10^{14}
Flint	7 - 10		0.45	0.4				
Nonex	4.2			0.25		0.28		
Photographic	7.5			0.8 - 1				
Plate	6.8 - 7.6			0.6 - 0.8				
Pyrex	4.2 - 4.9		0.5	0.7		0.54	335	10^{14}
Gutta percha	2.5 - 4.9						200 - 500	$5 \times 10^{14} - 10^{15}$
Lucite[7]	2.5 - 3	7	5	1.5 - 3	1.9		480 - 500	
Melamine formaldehyde	8	16					300	
Mica	2.5 - 8	0.2	0.3	0.2 - 6	0.02			2×10^{17}
Mica (clear India)	6.4 - 7.5	2	2	2	2		600 - 1500	
Mycalex	7.4			0.18			250	10^{13}
Mycalex (British)	6			0.3			350	
Mykroy	6.5 - 7			0.1 - 0.2			630	
Nylon	3.6			2.2				
Paper	2.0 - 2.6						1250	

FIGURE 4.43 TABLE OF DIELECTRIC CHARACTERISTICS (cont.)

Dielectric material[1]	Dielectric constant (K)	Power factor					Dielectric strength (puncture voltage)[2]	Volume resistivity[3]
		60 cycles	1 kc	1 Mc	10 Mc	100 Mc		
Paraffin wax (solid)	1.9 - 2.6			0.1 - 0.3			300	10^{15} - 10^{19}
Pemque	7.21			0.2				
Phenol:[8]								
Pure	5			1			400 - 475	1.5 x 10^{13}
Asbestos base	7.5			15			90 - 150	
Black molded	5 - 5.5			3.5			400 - 500	
Fabric base	5 - 6.5			3.5 - 11			150 - 500	
Mica-filled	5 - 6			0.8 - 1			475 - 600	
Paper base	3.8 - 5.5			2.5 - 4			650 - 750	10^{10} - 10^{13}
Yellow	5.3 - 5.4			0.36 - 0.7			500	
Polyethylene	2.3 - 2.4	0.02	0.02	0.02 - 0.05			1000	10^{17}
Polyindene	3	0.04						
Polystyrene[9]	2.4 - 2.9(2.6)	0.02	0.018	0.02	0.02	0.02	500 - 2500	10^{20}
Porcelain (dry process)	6.2 - 7.5			0.7 - 15			40 - 100	5 x 10^{3}
Porcelain (wet process)	6.5 - 7			0.6			150	
Pressboard (untreated)	2.9 - 4.5						125 - 300	
Pressboard (oiled)	5						750	
Quartz (fused)	3.5 - (3.8)	0.01	0.01	.015 - 0.03	0.01	0.05	200	10^{14} - 10^{18}
Rubber (hard)[10]	2 - 3.5(3)			0.5 - 1			450	10^{12} - 10^{15}
Shellac	2.5 - 4			0.09			900	10^{16}
Steatite:[11]								
"Commercial" grade	4.9 - 6.5	0.02	0.2	0.2	0.4	0.5		
"Low-loss" grade	4.4	0.02	0.2	0.2	0.18	0.13	150 - 315	10^{14} - 10^{15}
Titanium dioxide[12]	90 - 170		0.1	0.1				
Urea formaldehyde[13]	5 - 7	3 - 5	2 - 3	2 - 4	4		300 - 550	10^{12} - 10^{13}
Varnished cloth[14]	2 - 3.5			2 - 3			400 - 550	
Vinyl resins	4			1.4 - 1.7			400 - 500	10^{14}
Vitrolex	6.4			0.3				
Wood (dry oak)	2.5 - 6.8(3)		3.8	4.2				
Wood (paraffined maple)	4.1						115	
Polyisobutylene	2.4 - 2.5	0.04 - 5	0.05				500	10^{16}

1 Most data taken at 25°C.
2 Puncture voltage, in volts per mil. Most data apply to relatively thin sections and cannot be multiplied directly to give breakdown for thicker sections without added safety factor.
3 In ohm-cm.
4 Includes such products as Aladdinite, Ameroid, Galalith, Erinoid, Lactoid, etc.
5 Includes Fibestas, Lumerith, Nixonite, Plastaode, Tenite, etc.
6 Includes Amerith, Nitron, Nixonid, Pyralin, etc.
7 Methylmethacrylate resin.
8 Phenolaldehyde products include Acrolite, Bakelite, Catalin, Celeron, Dielecto, Dures, Durite, Formica, Gematone, Heresite, Indur, Makalot, Marblette, Micarta, Opalon, Prystal, Reninox, Synthane, Textolite, etc. Yellow bakelite is so-called "low-loss" bakelite.
9 Includes Amphenol 912A, Distrene, Intelin IN 45, Loalin, Lustron, Quartz Q, Rezoglas, Rhodolene M, Ronilla L, Styraflex, Styron, Trolitul, Victron, etc.
10 Also known as Ebonite.
11 Soapstone—Alberene, Alimag, Isolantite, Lava, etc.
12 Rutile. Used in low temperature-coefficient fixed condensers.
13 Includes Aldur, Beetle, Plaskoa, Pollopes, Prystal, etc.
14 Includes Empire cloth.

FIGURE 4.44 REFLECTIVITY OF HIGH-PURITY ALUMINUM AND OTHER METALS

Material	Total Reflectivity	Reflectivity Content	
		Specular %	Diffuse %
Polished 99% Al	72	92.0	8.0
Brytal-treated* 99% Al	65	80.0	20.0
Brytal-treated* 99.99% Al	84	99.0	1.0
Stainless Steel	60	97.0	3.0
Chromium Plate	63	99.7	0.3
Laquered Silver Plate	90	97.0	3.0

* Electropolishing and anodizing treatment

FIGURE 4.45 HEAT STORAGE SINKS

Material	Specific Heat BTU/lb/°F	Heat of Vaporization SL BTU/lb	Boiling Point °F		Freezing Point °F	Density lb/cu ft
			Sea Level	60,000 Ft		
Water	1.0	970	212	103	32	62
AN-F-28 Fuel	0.5	120*	100*	0*	‡	45
		160	375	275		
JP-4 Fuel	0.5	95*	225*	50*	‡	49
		140	525	350	‡	
Methyl Alcohol	0.6	480	150	50	‡	50
Dry Ice (solid)		248†	-110	-150	‡	98
Oxygen (liquid)	0.4	92	-298	-340	‡	71
Ammonia (liquid)	1.1	590	-28	-140	‡	43
Freon 12	0.2	70	-22	-112	‡	84

* Fractional Distillation Range

† Sublimitation

‡ Less than -65°F

Source: "Aircraft Materials and Processes", 5th Ed., G. F. Titterton: Copyright 1956, Pitman Publishing Corp.

FIGURE 4.46 SOUND IN LIQUIDS

In liquids, the velocity of sound is given by

$c = (1/K\ \rho_0)^{1/2}$ centimeters/second; $K = (47 \times 10^{-9})/981$ for most liquids

where

K = compressibility in centimeters/second^2/gram and may be regarded as constant.

Liquid	Temperature		Velocity	
	°C	°F	cm/sec	ft/sec
Alcohol, ethyl	12.5	54.5	1.24×10^5	4065
	20.0	68.0	1.17×10^5	3855
Benzene	20.0	68.0	1.32×10^5	4325
Carbon disulfide	20.0	68.0	1.16×10^5	3800
Chloroform	20.0	68.0	1.00×10^5	3280
Ether, ethyl	20.0	68.0	1.01×10^5	3310
Glycerin	20.0	68.0	1.92×10^5	6300
Mercury	20.0	68.0	1.45×10^5	1750
Pentaine	18.0	64.4	1.05×10^5	3440
	20.0	68.0	1.02×10^5	3340
Petroleum	15.0	59.0	1.33×10^5	4360
Turpentine	3.5	38.3	1.37×10^5	4490
	27.0	80.6	1.28×10^5	4195
Water, fresh	17.0	62.6	1.43×10^5	4685
Water, sea (36 parts/ million salinity)	15.0	59.0	1.505×10^5	4930

[Figure 4.47]

FIGURE 4.47 PHYSICAL PROPERTIES OF GASES

Gas		Wt, lb/1cu ft Std. Atmos. and 68 °F	Density Relative to Air	Gas Constant R, ft lb/lb °R	Melting Point, °F	Specific Heat per lb at Room Temperatures, Btu/lb °F			Boiling Point, °F	Density of Liquified Gas lb/ft³	
						c_p	c_v	$k = c_p/c_v$			
Helium	He	0.01039	0.138	386.30	-458	1.250	0.754	1.66	-452	9.18 at -456° F	
Argon	A	0.1037	1.377	38.70	-308	0.124	0.0743	1.67	-303	87.3	-303
Air	-	0.07528	1.000	53.30		0.241	0.1725	1.40		57.4	-233
Oxygen	O_2	0.08305	1.103	48.31	-360	0.217	0.1549	1.40	-297	71.1	-297
Nitrogen	N_2	0.07274	0.966	55.16	-346	0.247	0.1761	1.40	-321	50.4	-321
Hydrogen	H_2	0.005234	0.0695	766.80	-434	3.420	2.4350	1.40	-423	4.37	-423
Nitric Oxide	N_2O_2	0.07788	1.034	51.52		0.231	0.1648	1.40	-291	91.7	+60
Carbon Monoxide	CO	0.07269	0.965	55.19		0.243	0.1721	1.41	-310	53.7	-90
Steam		--	0.623	85.81		0.460	0.3600	1.28	-212	62.4	+39
Carbon Dioxide	CO_2	0.1142	1.516	35.13		0.205	0.1599	1.28	-109	48.0	+68
Ammonia	NH_3	0.04420	0.587	90.77		0.523	0.4064	1.29	-28	38.1	+61
Acetylene	C_2H_2	0.06754	0.897	59.40		0.350	0.2737	1.28	-118	24.9	+86
Methane		0.04163	0.553	96.37		0.593	0.4692	1.26	-258	25.9	-263
Ethylene		0.07280	0.967	55.11		0.400	0.3292	1.22	-155	13.1	+50
Boron Fluoride	BF_3	0.187	2.09								
Propane	C_3H_3	0.1254	1.407								
Sulfur Dioxide	SO_2	0.1827	2.048								
Triethyl Boron	CH_{33} B	0.157	1.76								

FIGURE 4.48 EQUATIONS FOR STRENGTH OF MATERIALS

Eq. 4.1. Tensile, Compressive or Shear Stress

$$s = \frac{F}{A} = E\epsilon$$

Eq. 4.2. Elongation

$$e = \frac{FL}{AE} = l\epsilon$$

Eq. 4.3. Strain due to a load

$$\epsilon = \frac{S}{E}$$

Eq. 4.4. Modulus of Elasticity

$$E = \frac{S}{\epsilon}$$

Eq. 4.5. Bending Stress

$$S_b = \frac{Mc}{I}$$

Eq. 4.6. Torsional Shear Stress

$$S_s = \frac{Tc}{J}$$

Eq. 4.7. Twist or Rotational Displacement

$$\theta = \frac{TL}{JG}$$

Eq. 4.8. Vertical Shear Stress

$$S_s = \frac{VQ}{Ib}$$

Eq. 4.9. Strain Energy per Unit Volume

$$U = \frac{1}{2}\frac{S^2}{E}$$

Eq. 4.10. Total Strain Energy

$$U = \frac{1}{2}\frac{S^2}{E}lA = \frac{1}{2}Fe$$

Eq. 4.11. Stress due to Simultaneous Axial and Transverse loading

$$S_{max} = \frac{F}{A} \pm \frac{M'c}{I}$$

Eq. 4.12. Stress due to combined Bending and Torsion

$$S_{b_{max}} = \frac{M'r}{I} \qquad \text{where } M' = \frac{1}{2}\left(M + \sqrt{M^2 + T^2}\right)$$

$$S_{s_{max}} = \frac{T'r}{J} \qquad T' = \sqrt{M^2 + T^2}$$

Eq. 4.13. Deflection of a Beam

$$y = C\frac{Wl^3}{EI} = \frac{Sl^2}{Ed} \qquad d = \text{depth}$$

(See Table 48A for values of C)

FIGURE 4.48 (A) SHEAR, MOMENT, AND DEFLECTION FORMULAS FOR BEAMS*

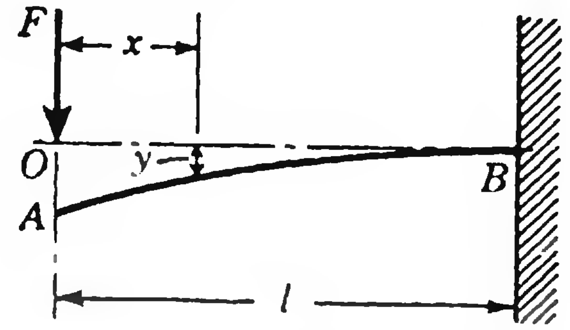
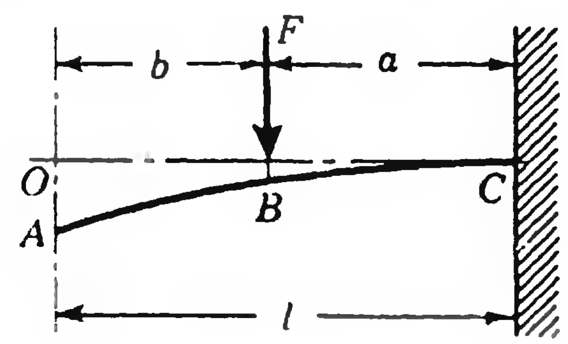
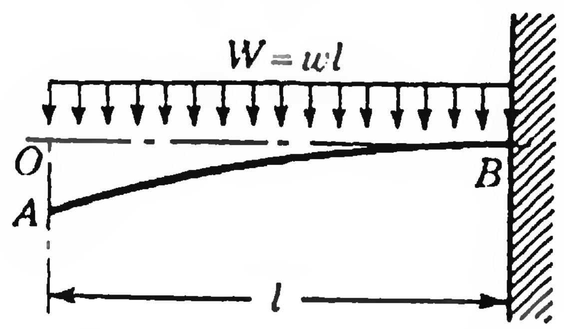
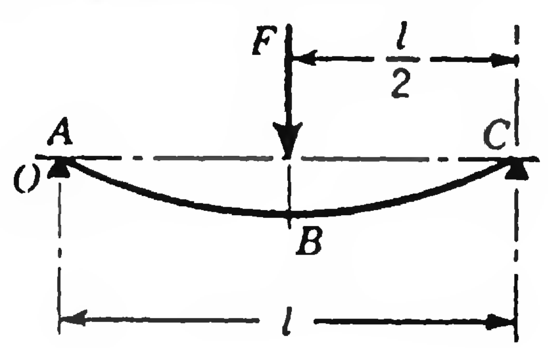
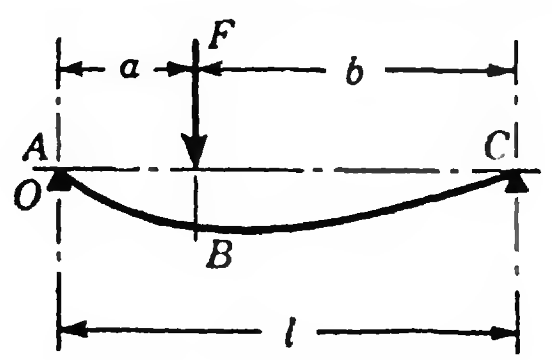
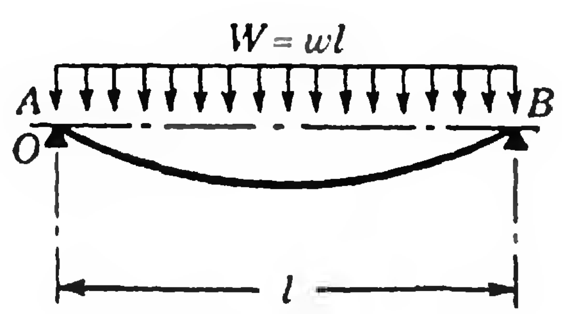
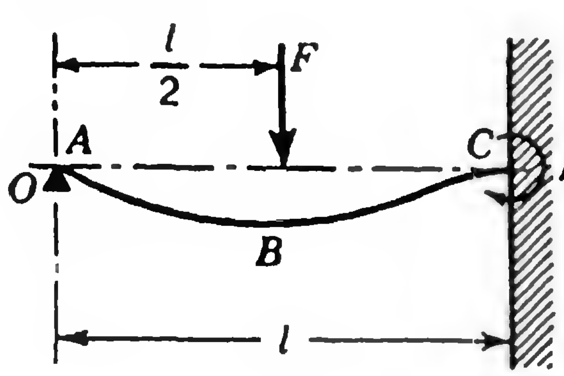
Loading, support, and reference number	Reactions R_1 and R_2, vertical shear V	Bending moment M, maximum bending moment	Deflection y and maximum deflection
1. Cantilever, end load 	$R_2 = +F$ $V = -F$	$M = -Fx$ Max $M = -Fl$ at B	$y = -\frac{1}{6}\frac{F}{EI}(x^3 - 3l^2x + 2l^3)$ Max $y = -\frac{1}{3}\frac{Fl^3}{EI}$ at A
2. Cantilever, intermediate load 	$R_2 = +F$ A to B: $V = 0$ B to C: $V = -F$	A to B: $M = 0$ B to C: $M = -F(x - b)$ Max $M = -Fa$ at C	A to B: $y = -\frac{1}{6}\frac{F}{EI}(-a^3 + 3a^2l - 3a^2x)$ B to C: $y = -\frac{1}{6}\frac{F}{EI}[(x - b)^3 - 3a^2(x - b) + 2a^3]$ Max $y = -\frac{1}{6}\frac{F}{EI}(3a^2l - a^3)$
3. Cantilever, uniform load 	$R_2 = +W$ $V = -\frac{W}{l}x$	$M = -\frac{1}{2}\frac{W}{l}x^2$ Max $M = -\frac{1}{2}Wl$ at B	$y = -\frac{1}{24}\frac{W}{EIl}(x^4 - 4l^3x + 3l^4)$ Max $y = -\frac{1}{8}\frac{Wl^3}{EI}$
4 End supports, center load 	$R_1 = +\frac{1}{2}F$ $R_2 = +\frac{1}{2}F$ A to B: $V = +\frac{1}{2}F$ B to C: $V = -\frac{1}{2}F$	A to B: $M = +\frac{1}{2}Fx$ B to C: $M = +\frac{1}{2}F(l - x)$ Max $M = +\frac{1}{4}Fl$ at B	A to B: $y = -\frac{1}{48}\frac{F}{EI}(3l^2x - 4x^3)$ Max $y = -\frac{1}{48}\frac{Fl^3}{EI}$ at B

FIGURE 4.48 (A) SHEAR, MOMENT, AND DEFLECTION FORMULAS FOR BEAMS (cont.)

Loading, support, and reference number	Reactions R_1 and R_2, vertical shear V	Bending moment M, maximum bending moment	Deflection y and maximum deflection
5. End supports, intermediate load 	$R_1 = +F\frac{b}{l}$ $\quad R_2 = +F\frac{a}{l}$ A to B: $V = +F\frac{b}{l}$ B to C: $V = -F\frac{a}{l}$	A to B: $M = +F\frac{b}{l}x$ B to C: $M = +F\frac{a}{l}(l - x)$ Max $M = +F\frac{ab}{l}$ at B	A to B: $y = -\frac{Fbx}{6EIl}[2l(l - x) - b^2 - (l - x)^2]$ B to C: $y = -\frac{Fa(l - x)}{6EIl}[2lb - b^2 - (l - x)^2]$ Max $y = -\frac{Fab}{27EIl}(a + 2b)\sqrt{3a(a + 2b)}$ at $x = \sqrt{\frac{1}{3}a(a + 2b)}$ when $a > b$
6. End supports, uniform load 	$R_1 = +\frac{1}{2}W$ $\quad R_2 = +\frac{1}{2}W$ $V = \frac{1}{2}W\left(1 - \frac{2x}{l}\right)$	$M = \frac{1}{2}W\left(x - \frac{x^2}{l}\right)$ Max $M = +\frac{1}{8}Wl$ at $x = \frac{1}{2}l$	$y = -\frac{1}{24}\frac{Wx}{EIl}(l^3 - 2lx^2 + x^3)$ Max $y = -\frac{5}{384}\frac{Wl^3}{EI}$ at $x = \frac{1}{2}l$
7. One end fixed, one end supported, center load 	$R_1 = \frac{5}{16}F$ $\quad R_2 = \frac{11}{16}F$ $M_2 = \frac{3}{16}Fl$ A to B: $V = +\frac{5}{16}F$ B to C: $V = -\frac{11}{16}F$	A to B: $M = \frac{5}{16}Fx$ B to C: $M = F(\frac{1}{2}l - \frac{11}{16}x)$ Max $+ M = \frac{5}{32}Fl$ at B Max $- M = -\frac{3}{16}Fl$ at C	A to B: $y = \frac{1}{96}\frac{F}{EI}(5x^3 - 3l^2x)$ B to C: $y = \frac{1}{96}\frac{F}{EI}\left[5x^3 - 16\left(x - \frac{l}{2}\right)^3 - 3l^2x\right]$ Max $y = -0.00932\frac{Fl^3}{EI}$ at $x = 0.4472l$

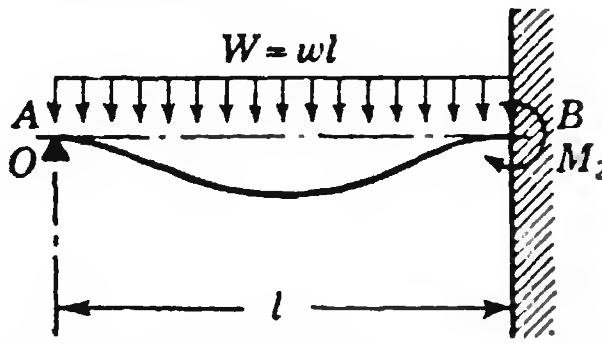
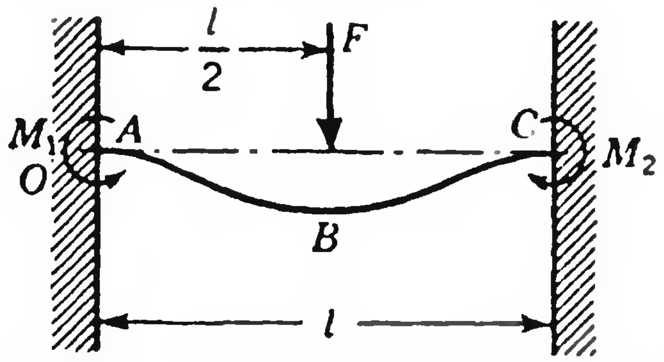
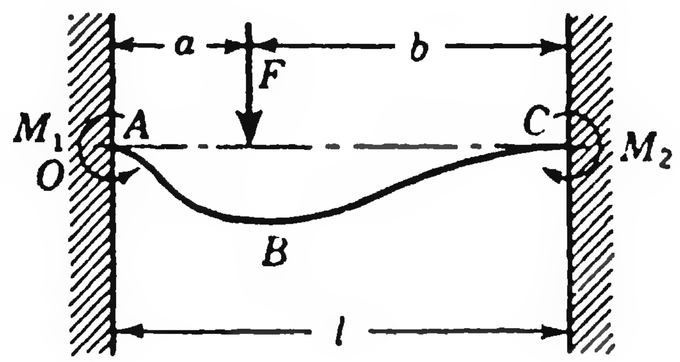
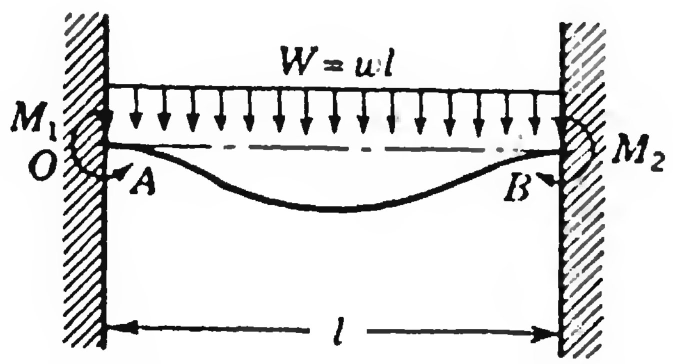
8. One end fixed, one end supported, uniform load 	$R_1 = \frac{3}{8}W$ $R_2 = \frac{5}{8}W$ $M_2 = \frac{1}{8}Wl$ $V = W\left(\frac{3}{8} - \frac{x}{l}\right)$	$M = W\left(\frac{3}{8}x - \frac{1}{2}\frac{x^2}{l}\right)$ Max $+M = \frac{9}{128}Wl$ at $x = \frac{3}{8}l$ Max $-M = -\frac{1}{8}Wl$ at B	$y = \frac{1}{48}\frac{W}{EIl}(3lx^3 - 2x^4 - l^3x)$ Max $y = -0.0054\frac{Wl^3}{EI}$ at $x = 0.4215l$
9. Both ends fixed, center load 	$R_1 = \frac{1}{2}F$ $R_2 = \frac{1}{2}F$ $M_1 = \frac{1}{8}Fl$ $M_2 = \frac{1}{8}Fl$ A to B: $V = +\frac{1}{2}F$ B to C: $V = -\frac{1}{2}F$	A to B: $M = \frac{1}{8}F(4x - l)$ B to C: $M = \frac{1}{8}F(3l - 4x)$ Max $+M = \frac{1}{8}Fl$ at B Max $-M = -\frac{1}{8}Fl$ at A and C	A to B: $y = -\frac{1}{48}\frac{F}{EI}(3lx^2 - 4x^3)$ Max $y = -\frac{1}{192}\frac{Fl^3}{EI}$ at B
10. Both ends fixed, intermediate load 	$R_1 = \frac{Fb^2}{l^3}(3a + b)$ $R_2 = \frac{Fa^2}{l^3}(3b - a)$ $M_1 = F\frac{ab^2}{l^2}$ $M_2 = F\frac{a^2b}{l^2}$ A to B: $V = R_1$ B to C: $V = R_1 - F$	A to B: $M = -F\frac{ab^2}{l^2} + R_1x$ B to C: $M = -F\frac{ab^2}{l^2} + R_1x - F(x - a)$ Max $+M = -F\frac{ab^2}{l^2} + R_1a$ at B Max $-M = -M_1$ when $a < b$ Max $-M = -M_2$ when $a > b$	A to B: $y = \frac{1}{6}\frac{Fb^2x^2}{EIl^3}(3ax + bx - 3al)$ B to C: $y = \frac{1}{6}\frac{Fa^2(l - x)^2}{EIl^3}[(3b + a)(l - x) - 3bl]$ Max $y = -\frac{2}{3}\frac{F}{EI}\frac{a^3b^2}{(3a + b)^2}$ at $x = \frac{2al}{3a + b}$ if $a > b$ Max $y = -\frac{2}{3}\frac{F}{EI}\frac{a^2b^3}{(3b + a)^2}$ at $x = l - \frac{2bl}{3b + a}$ if $a < b$
11. Both ends fixed, uniform load 	$R_1 = \frac{1}{2}W$ $R_2 = \frac{1}{2}W$ $M_1 = \frac{1}{12}Wl$ $M_2 = \frac{1}{12}Wl$ $V = \frac{1}{2}W\left(1 - \frac{2x}{l}\right)$	$M = \frac{1}{2}W\left(x - \frac{x^2}{l} - \frac{1}{6}l\right)$ Max $+M = \frac{1}{24}Wl$ at $x = \frac{1}{2}l$ Max $-M = -\frac{1}{12}Wl$ at A and B	$y = \frac{1}{24}\frac{Wx^2}{EIl}(2lx - l^2 - x^2)$ Max $y = -\frac{1}{384}\frac{Wl^3}{EI}$ at $x = \frac{1}{2}l$

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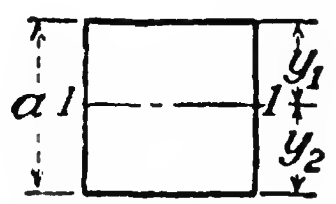
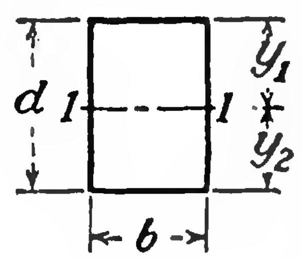
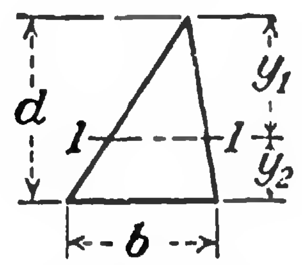
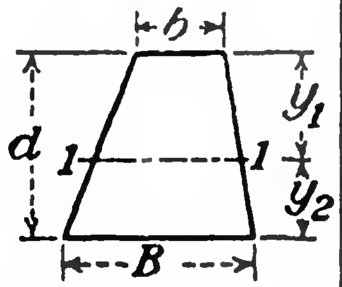
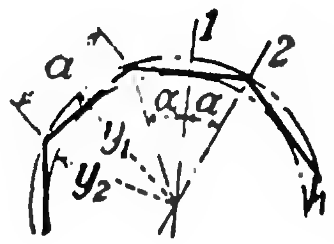
FIGURE 4.48 (B) PROPERTIES OF SECTIONS*

Form of section	Area A	Distance from centroid to extremities of section y_1, y_2	Moments of inertia I_1 and I_2 about principal central axes 1 and 2	Radii of gyration, r_1 and r_2, about principal central axes
1. Square 	$A = a^2$	$y_1 = y_2 = \frac{1}{2}a$	$I_1 = I_2 = I_3 = \frac{1}{12}a^4$	$r_1 = r_2 = r_3 = 0.289a$
2. Rectangle 	$A = bd$	$y_1 = y_2 = \frac{1}{2}d$	$I_1 = \frac{1}{12}bd^3$	$r_1 = 0.289d$
3. Triangle 	$A = \frac{1}{2}bd$	$y_1 = \frac{2}{3}d$ $y_2 = \frac{1}{3}d$	$I_1 = \frac{1}{36}bd^3$	$r_1 = 0.2358d$
4. Trapezoid 	$A = \frac{1}{2}(B + b)d$	$y_1 = d\frac{2B + b}{3(B + b)}$ $y_2 = d\frac{B + 2b}{3(B + b)}$	$I_1 = \frac{d^3(B^2 + 4Bb + b^2)}{36(B + b)}$	$r_1 = \frac{d}{6(B + b)}\sqrt{2(B^2 + 4Bb + b^2)}$
5. Regular polygon with n sides 	$A = \frac{1}{4}na^2 \cot \alpha$	$y_1 = \frac{a}{2 \sin \alpha}$ $y_2 = \frac{a}{2 \tan \alpha}$	$I_1 = \frac{A(6y_1^2 - a^2)}{24}$ $I_2 = \frac{A(12y_2^2 + a^2)}{48}$	$r_1 = \sqrt{\frac{6y_1^2 - a^2}{24}}$ $r_2 = \sqrt{\frac{12y_2^2 + a^2}{48}}$

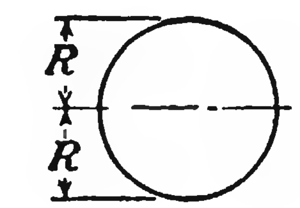
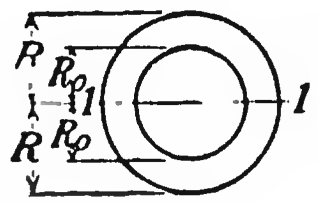
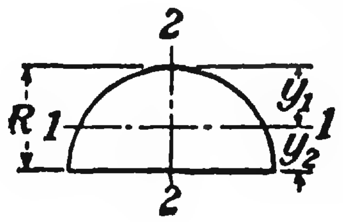
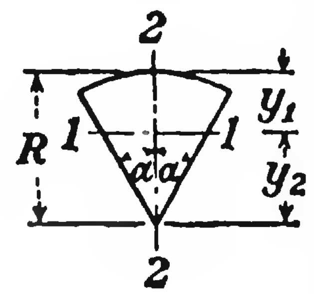
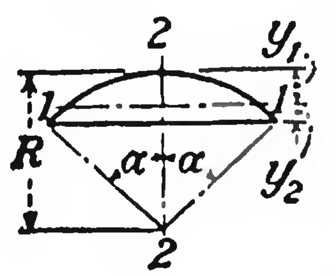
6 Solid circle 	$A = \pi R^2$	$y_1 = y_2 = R$	$I = \frac{1}{4}\pi R^4$	$r = \frac{1}{2}R$
7. Hollow circle 	$A = \pi(R^2 - R_0^2)$	$y_1 = y_2 = R$	$I = \frac{1}{4}\pi(R^4 - R_0^4)$	$r = \sqrt{\frac{1}{4}(R^2 + R_0^2)}$
8. Solid semicircle 	$A = \frac{1}{2}\pi R^2$	$y_1 = 0.5756R$ $y_2 = 0.4244R$	$I_1 = 0.1098R^4$ $I_2 = \frac{1}{8}\pi R^4$	$r_1 = 0.2643R$ $r_2 = \frac{1}{2}R$
9. Circular sector 	$A = \alpha R^2$	$y_1 = R\left(1 - \frac{2\sin\alpha}{3\alpha}\right)$ $y_2 = 2R\frac{\sin\alpha}{3\alpha}$	$I_1 = \frac{1}{4}R^4\left[\alpha + \sin\alpha\cos\alpha - \frac{16\sin^2\alpha}{9\alpha}\right]$ $I_2 = \frac{1}{4}R^4[\alpha - \sin\alpha\cos\alpha]$	$r_1 = \frac{1}{2}R\sqrt{1 + \frac{\sin\alpha\cos\alpha}{\alpha} - \frac{16\sin^2\alpha}{9\alpha^2}}$ $r_2 = \frac{1}{2}R\sqrt{1 - \frac{\sin\alpha\cos\alpha}{\alpha}}$
10. Circular segment 	$A = \frac{1}{2}R^2(2\alpha - \sin 2\alpha)$	$y_1 = R\left(1 - \frac{4\sin^3\alpha}{6\alpha - 3\sin 2\alpha}\right)$ $y_2 = R\left(\frac{4\sin^3\alpha}{6\alpha - 3\sin 2\alpha} - \cos\alpha\right)$	$I_1 = R^4\left[\frac{1}{8}(2\alpha - \sin 2\alpha)\left(1 + \frac{2\sin^3\alpha\cos\alpha}{\alpha - \sin\alpha\cos\alpha}\right) - \frac{8}{9}\frac{\sin^6\alpha}{2\alpha - \sin 2\alpha}\right]$ $I_2 = R^4\left[\frac{1}{8}(2\alpha - \sin 2\alpha) - \frac{1}{12}\frac{(2\alpha - \sin 2\alpha)\sin^3\alpha\cos\alpha}{\alpha - \sin\alpha\cos\alpha}\right]$	$r_1 = \frac{1}{2}R\sqrt{1 + \frac{2\sin^3\alpha\cos\alpha}{\alpha - \sin\alpha\cos\alpha} - \frac{64}{9}\frac{\sin^6\alpha}{(2\alpha - \sin 2\alpha)^2}}$ $r_2 = \frac{1}{2}R\sqrt{1 - \frac{2\sin^3\alpha\cos\alpha}{3(\alpha - \sin\alpha\cos\alpha)}}$

FIGURE 4.48 (B) PROPERTIES OF SECTIONS (cont.)

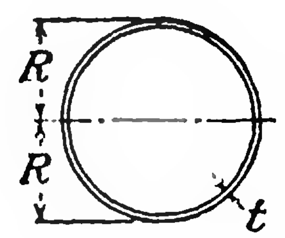
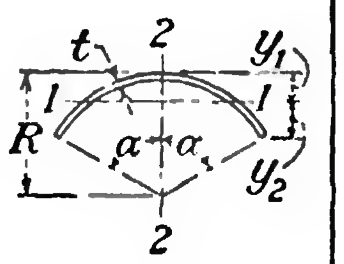
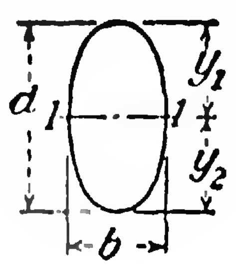
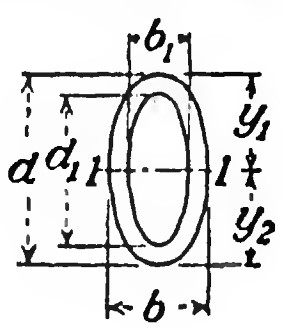
Form of section	Area A	Distance from centroid to extremities of section y_1, y_2	Moments of inertia I_1 and I_2 about principal central axes 1 and 2	Radii of gyration, r_1 and r_2, about principal central axes
11. Very thin annulus 	$A = 2\pi Rt$	$y_1 = y_2 = R$	$I = \pi R^3 t$	$r = 0.707R$
12. Sector of thin annulus 	$A = 2\alpha Rt$	$y_1 = R\left(1 - \frac{\sin\alpha}{\alpha}\right)$ $y_2 = R\left(\frac{\sin\alpha}{\alpha} - \cos\alpha\right)$	$I_1 = R^3 t\left(\alpha + \sin\alpha\cos\alpha - \frac{2\sin^2\alpha}{\alpha}\right)$ $I_2 = R^3 t(\alpha - \sin\alpha\cos\alpha)$	$r_1 = R\sqrt{\frac{\alpha + \sin\alpha\cos\alpha - 2\sin^2\alpha/\alpha}{2\alpha}}$ $r_2 = R\sqrt{\frac{\alpha - \sin\alpha\cos\alpha}{2\alpha}}$
13. Solid ellipse 	$A = \frac{1}{4}\pi bd$	$y_1 = y_2 = \frac{1}{2}d$	$I_1 = \frac{1}{64}\pi bd^3$	$r_1 = \frac{1}{4}d$
14. Hollow ellipse 	$A = \frac{1}{4}\pi(bd - b_1d_1)$	$y_1 = y_2 = \frac{1}{2}d$	$I_1 = \frac{1}{64}\pi(bd^3 - b_1d_1^3)$	$r_1 = \frac{1}{4}\sqrt{\frac{bd^3 - b_1d_1^3}{bd - b_1d_1}}$

FIGURE 4.49 STRUCTURAL DESIGN RATIOS

For preliminary design or for changing proportions of existing designs, use of certain ratios is convenient. The general relations are given in Table A and the ratios for strength and rigidity equations are given in Table B. Further corrections or proportioning must be considered for modifying the ratio of stresses to allow for velocity differences, acceleration loads, minimum gages or sizes, choice of standard sizes, design criteria other than strength or rigidity.

TABLE A

Eq. 4.14 Linear

$$n = \frac{b_2}{b_1} = \frac{t_2}{t_1} = \frac{h_2}{h_1} = \frac{d_2}{d_1}$$

$$L_n = \frac{L_2}{L_1} \text{ (not necessarity equal to n)}$$

$$b_n = n = \frac{b_2}{b_1} \text{ (where = any or all linear cross sectional dimensions)}$$

$$k_n = n = \frac{k_2}{k_1} = \sqrt{\frac{I_2}{A_2} \cdot \frac{A_1}{I_1}} \text{ (ratio of radii of gyration)}$$

Eg. 4.15 Cross-Sectional

$$A_n = n^2 = \frac{A_2}{A_1} = \left(\frac{b_2}{b_1}\right)^2 = \frac{b_2\ h_2}{b_1\ h_1}$$

$$Z_n = n^3 = \frac{Z_2}{Z_1} = \frac{I_2}{C_2}\frac{C_1}{I_1} = \frac{b_2}{b_1}\left(\frac{h_2}{h_1}\right)^2 = \left(\frac{b_2}{b_1}\right)^3$$

$$I_n = n^4 = \frac{I_2}{I_1} = \frac{b_2}{b_1}\left(\frac{h_2}{h_1}\right)^3 = \left(\frac{b_2}{b_1}\right)^4$$

$$J_n = n^4$$

$$w_n = n^2 = \frac{w_2}{w_1} = \frac{\rho_2\ A_2}{\rho_1\ A_1} \text{ ratio of weights per unit length}$$

Eg. 4.16 Three Dimensional ($L_n = n$)

$$V'_n = n^3 = \frac{V'_2}{V'_1} = \left(\frac{b_2}{b_1}\right)^3 = \frac{b_2\ h_2\ L_2}{b_1\ h_1\ L_1}$$

$$W_n = n^3 = \frac{W_2}{W_1} = \frac{\rho_2\ V'_2}{\rho_1\ V'_1} \text{ ratio of total weights}$$

Eq. 4.17 Loads, Stresses, Deflections

$$F_n = \frac{F_2}{F_1} \text{ ratio of loads}$$

$$s_n = \frac{s_2}{s_1} = \frac{(s_{ult})_2\ N_1}{(s_{ult})_1\ N_2} = \frac{(s_y)_2\ N'_1}{(s_y)_1\ N'_2} \qquad a = \frac{\theta}{L}$$

$$T = Fe \qquad M = CFL = CwL^2 \quad \text{where } wL = F$$

$$y = \frac{\epsilon}{L} = \frac{KFL^2}{EI} = \frac{KwL^3}{EI}$$

FIGURE 4.49 STRUCTURAL DESIGN RATIOS (cont.)

These last two equations are the general equations for a beam where C and K are the coefficients of moment and deflection respectively and take into account the load pattern, continuity over supports, fixity of supports, cantilever effects. These coefficients are assumed to be unchanged for the old and the new design.

The load pattern is the relative positions, directions, magnitudes, and linear lengths of application of a series of concentrated or uniformly distributed loads on a beam or other member. Load patterns must be the same for the old and the new design.

Cross sections of the old and the new design must be geometrically similar in the linear ratio n.

TABLE B
RATIOS FOR STRENGTH AND RIGIDITY EQUATIONS

1. Direct Stress

Since average tension and compression stresses ($s = F/A$) and shear stresses in beams ($S = V/A_{web}$) are independent of length

$$F_n = s_n A_n = s_n n^2$$

For equal stresses in new and old designs

$$F_n = n^2$$

or

$$n = \sqrt{F_n}$$

2. Elongation or Deflection

Unit deflection, y, can be written

$$y = \frac{\epsilon}{L} = \frac{FL}{LAE} = \frac{F}{AE}$$

Therefore,

$$F_n = y_n A_n E_n$$

If unit deflection and modulus of elasticity is same in new and old design

$$F_n = n^2$$

3. Torsion

Moment arms are assumed to be in same linear ratio n as other dimensions

Since $T = Fe$

$$F_n = T_n/e_n = T_n/n$$

Also

$$S_s = Tc/J = T/Z_p \quad \text{(round section)}$$

$$T_n = (S_s)_n (Z_p)_n = (S_s)_n n^3$$

For equal stresses

$$F_n = n^2 = \sqrt[3]{(T_n)^2}$$

4. Cylinders

Thin wall

$$s = pD/2t$$

$$p_n = s_n t_n / D_n = s_n$$

Thick wall

$$s = p\,\frac{D^2 + d^2}{D^2 - d^2}$$

$$p_n = s_n$$

External pressure

$$s = p\,\frac{2D^2}{D^2 - d^2}$$

$$p_n = s_n$$

For equal pressures

$$F_n = p_n n^2 = n^2$$

5. Flexures of Beams

Moment arms assumed to be in same linear ratio n as the beams

$$s = Mc/I = M/Z$$

$$s_n = M_n/Z_n$$

For equal stresses

$$M_n = n^3$$

For couple

$$M = Fe = C'FL \text{ where } e = C'L$$

For concentrated load

$$M = CFL$$

Thus for spans in same linear ratio n,

$$s = CFL/Z$$

and

$$F_n = s_n Z_n / L_n = s_n n^2$$

FIGURE 4.49 RATIOS FOR STRENGTH AND RIGIDITY EQUATIONS (cont.)

For equal stresses

$$F_n = n^2$$

For uniformly distributed load

$$F = pbl = wl = C''wL$$

and

$$p_n = F_n / b_n l_n = n^2 / n^2 = \text{unity}$$

Also

$$w_n = F_n / l_n = n$$

Thus for condition $F_n = n^2$ loads per unit area are same in new and old design and loads per unit length are in ratio n.

6. Radius of Curvature (Corresponding to case 5)

$$R = EI/M$$

Thus

$$M_n = \frac{E_n I_n}{R_n} = \frac{n^4}{R_n}$$

$$M_n = \frac{n^4}{n} = n^3$$

For equal moduli of elasticity and radii of curvature in same linear ratio n

$$F_n = \frac{M_n}{l_n} = \frac{n^3}{n} = n^2$$

7. Linear Deflection (Corresponding to Case 5)

$$y = \frac{\epsilon}{L} = \left(\frac{1}{L}\right)\left(\frac{KFL^3}{EI}\right)$$

$$y = \left(\frac{1}{L}\right)\left(\frac{K'ML^2}{EI}\right)$$

$$M_n = \frac{y_n E_n I_n}{L_n} = n^3$$

For equal unit deflections, equal moduli of elasticity, and spans in same linear ratio n

$$F_n = M_n / n = n^2$$

8. Shafts—ASME Code

$$S_s = \frac{16}{\pi D^3}\left[(K_t T)^2 + (K_m M)^2\right]^{\frac{1}{2}}$$

$$M = CFL \text{ and } T = F'e = C'FL$$

where e is assumed to be constant proportion of L and forces F and F' are in constant ratio

$$s_s = \frac{16}{\pi D^3}\left[(K'FL)^2 + (K''FL)^2\right]^{\frac{1}{2}}$$

$$s_s = KFL/D^3$$

$$F_n = (s_s)_n D_n^3 / L_n = (s_s)_n n^2$$

For equal stresses and lengths in constant ratio n

$$F_n = n^2$$

9. Combined Shear and Torsion

$$(s_s)_{max} = \frac{1}{2}s_t + \left[(s_s)^2 + \frac{1}{2}(s_t)^2\right]^{\frac{1}{2}}$$

$$= \frac{F}{2A} + \left[\left(\frac{2KF}{2A}\right)^2 + \left(\frac{F}{2A}\right)^2\right]^{\frac{1}{2}}$$

$$= \frac{F}{2A}\left(1 + \sqrt{4K \quad +1}\right)$$

$$F_n = S_n A = S_n n^2$$

For equal stresses

$$F_n = n^2$$

Thus if forces in new and old design are in constant proportion, relationship for simple stress (Case 1) also applies to combined stress.

10. Combined Axial Load and Moment

$$s = \frac{F}{A} + \frac{F'e}{Z} = F\left(\frac{Z + KAe}{AZ}\right)$$

$$s = Fb^3K'/b^5$$

where F' = KF (Case 8) and e is a constant proportion of linear cross section dimension b.

$$F_n = s_n n^2$$

For equal stresses

$$F_n = n^2$$

11. Euler Column

Limiting axial load is

$$F = \frac{C\pi^2 EAk^2}{L^2}$$

$$F_n = A_n (k_n)^2/(L_n)^2$$

FIGURE 4.49 RATIOS FOR STRENGTH AND RIGIDITY EQUATIONS (cont.)

For equal moduli of elasticity, similar end conditions, and lengths in same linear ratio n

$$F_n = n^2$$

12. Torsional Deflection

$$T = Fe$$

$$F_n = T_n/e_n = T_n/n$$

$$a = \theta/L = TL/LGJ$$

Therefore

$$T_n = a_n G_n J_n$$

For equal unit deflections and equal shear moduli

$$T_n = n^4$$

Also $$F_n = a_n G_n j_n/e_n$$

For equal unit deflections and equal shear moduli

$$F_n = n^3$$

Note: This is the only case where $F_n = n^2$ for strength but not for deflection.

13. Flexure of Beams — I

(For beams with geometrically similar cross sections in ratio n but in different spans, carrying equal loads.)

$$s = CFL/Z$$

$$Z_n = F_n L_n/s_n$$

Since F_n = unity

$$s_n = L_n/n^3$$

For equal stresses

$$n^3 = L_n = L_2/L_1$$

$$w_n = L_n A_n = n^5$$

14. Beam Deflection (Corresponding to Case 13)

$$y = \frac{\epsilon}{L} = \frac{KFL^3}{LEZ}$$

$$w_n = \frac{F_n(L_n)^2}{y_n E_n}$$

For equal unit deflections, equal loads and equal moduli of elasticity

$$I_n = (L_n)^2$$

$$n^4 = (L_n)^2 \quad \text{or} \quad n = \sqrt{L_n}$$

FIGURE 4.49 RATIOS FOR STRENGTH AND RIGIDITY EQUATIONS (cont.)

15. Flexure of Beams — II

(For beams with geometrically similar cross sections in linear ratio n, with different spans and carrying different total loads. Load patterns — relative positions and relative magnitudes of a series of loads — must be the same). From Case 13,

$$n^3 = F_n L_n / s_n$$

For equal stresses

$$n^3 = F_n L_n$$

$$F_2 L_2 / F_1 L_1$$

$$w_n = L_n A_n = n^5 / F_n$$

16. Flexure of Beams — III

Flexure of beams of different spans, carrying uniformly distributed loads of equal magnitude per unit length. Load patterns must be the same, and beams geometrically similar cross sections in linear ratio n.

$$s = \frac{C' \text{ w } 1 \text{ L}}{Z} = \frac{C \text{ w } L^2}{Z}$$

$$Z_n = \frac{w_n \ (L_n)^2}{s_n}$$

For equal stresses,

$$n^3 = \frac{(L_n)^2}{s_n} = (L_n)^2$$

$$n = \sqrt[3]{(L_n)^2}$$

$$W_n = L_n A_n = \sqrt{n^3 \cdot n^2}$$

$$= \sqrt{n^7} = \sqrt[3]{(L_n)^7}$$

17. Flexure of Beams — IV

For beams of different spans carrying their own dead weight, or carrying uniformly distributed loads per unit length such that ratio of unit loads equals ratio of beam cross sectional areas ($w_n = n^2$). Load patterns must be same and cross sections in linear ratio n.

$$Z_n = w_n (L_n)^2 / s_n$$

$$n^3 = n^2 (L_n)^2 / s_n$$

For equal stresses

$$n = (L_n)^2$$

$$w_n = L_n A_n = \sqrt{n} \ n^2 = \sqrt{n^5} = (L_n)^5$$

If $L_n = n$ $\quad s_n = n$, and $F = n^3$

Note: Beam webs in must be checked for shear by method of — Case 1.

FIGURE 4.50 SAFETY FACTORS*

Suggested safety factors to be applied to limit loads for use in the design of guided missile structures are as follows:

1. All structures except as otherwise noted		1.00
2. Handling Loads		1.15
3. Castings		1.00
(Castings are to be designed and inspected in accordance with specification MIL-C-6021 except that their use is unrestricted)		
4. Fittings		
a. Analyzed but not proof-tested		1.15
b. Proof-tested		1.00
(When yield strength is above 0.85 of ultimate, use 0.85 ultimate as the yield strength)		
c. Rivets, bolts, or pins used for fitting attachments		1.15
5. Bearings	In accordance with	ANC-5
6. Joints		
a. Fusion Welding	In accordance with	ANC-5
b. Spot Welding	In accordance with	ANC-5
c. Resistance Seam Welding	Established by test	
d. Riveted, bolted, or pinned		1.00
7. Pressure Vessels		
a. That offer an explosive hazard to personnel		1.50 to 2.00
b. Pressurized remote from personnel		1.00

* ANC-5 "Strength of Metal Aircraft Elements"

FIGURE 4.51(A) VIBRATION FORMULAS

Eq. 4.18 Harmonic Motion

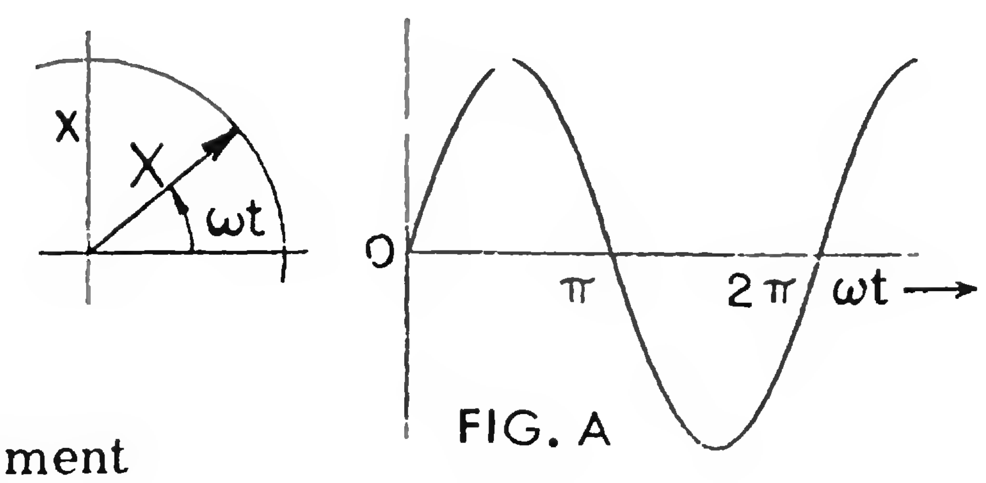


FIG. A

Displacement

$$x = X \sin \omega t$$

Period

$$\omega \tau = 2\pi; \ \tau = \frac{2\pi}{\omega}$$

FIGURE 4.51A VIBRATION FORMULAS (cont.)

Frequency

$$f = \frac{\omega}{2\pi}$$

Velocity

$$v = \frac{dx}{dt} = \omega X \cos \omega t = \omega X \sin \left(\omega t + \frac{\pi}{2}\right)$$

Acceleration

$$a = \frac{d^2x}{dt} = - \omega^2 X \sin \omega t = \omega^2 X \sin (\omega t + \pi)$$

Complex plane

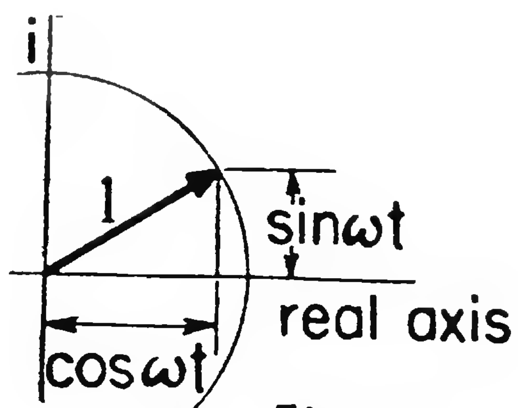


FIG. B

$$x = Xe^{i\omega t} \qquad i = \sqrt{-1}$$

$$e^{i\omega t} = \cos \omega t + i \sin \omega t$$

$$\frac{d^2x}{dt^2} + \omega^2 x = 0$$

Eq. 4.19 Single Degree of Freedom System

$$m = \frac{w}{g}$$

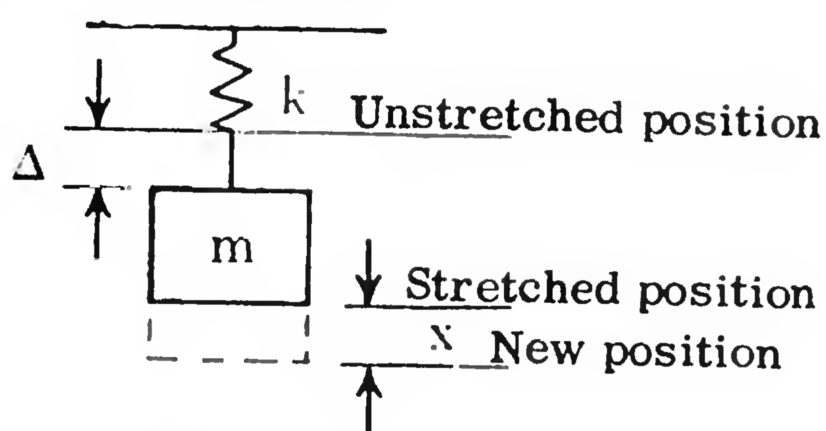


FIG. C

a. Undamped

Period

$$\tau = \frac{2\pi}{\omega} = 2\pi \sqrt{\frac{k}{m}}$$

Natural frequency

$$f_n = \frac{1}{2\pi} \sqrt{\frac{k}{m}} = \frac{1}{2\pi} \sqrt{\frac{g}{\Delta}}$$

$$\omega_n = \sqrt{\frac{k}{m}}$$

FIGURE 4.51A VIBRATION FORMULAS (cont.)

General forms of the equation of motion

$$x = A \sin \omega t + B \cos \omega t$$

$$x = Ae^{i\omega t} + B\bar{e}^{i\omega t}$$

A and B are arbitrary constants.

b. Damped - Free

Equation of motion

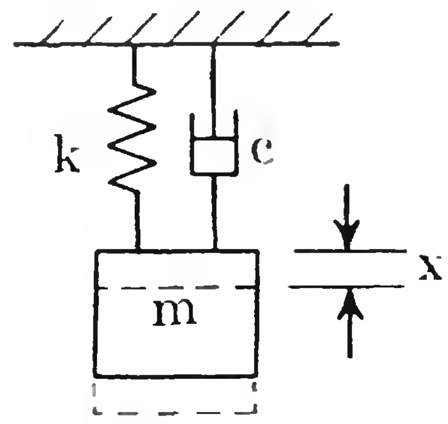


FIG. D

$$m\ddot{x} = -c\dot{x} - kx$$

$$x = Ae^{s_1 t} + BE^{s_2 t}$$

$$\text{where, } s_{1,2} = -\frac{c}{2m} \pm \sqrt{\left(\frac{c}{2m}\right)^2 - \frac{k}{m}}$$

$$x = e^{-\frac{mt}{c}} (A \sin \omega_{nd} t + B \cos \omega_{nd} t)$$

Critical damping

$$c_c = 2m\sqrt{\frac{k}{m}} = \omega_{nd} = 2m\omega_{nd}$$

$$\zeta = \frac{c}{c_c}$$

(For characteristic damping curves, see Fig. 10.58)

Logarithmic decrement - Viscous Damping

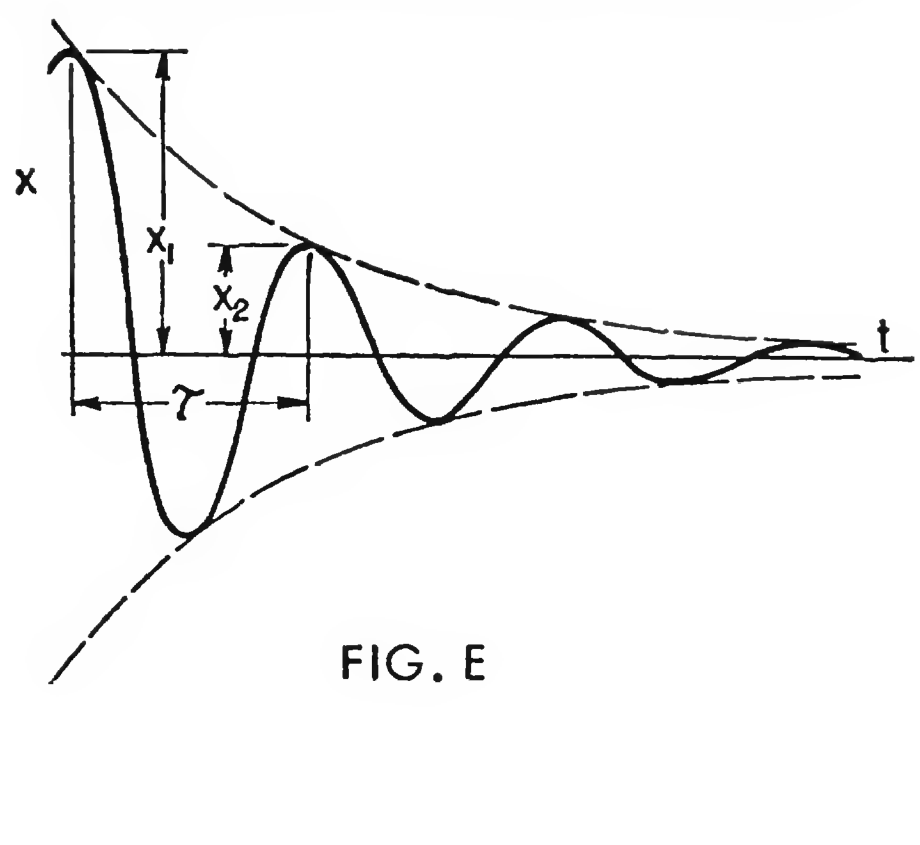


FIG. E

$$\delta = \log \frac{x_1}{x_2} = \frac{\Delta w}{2w}$$

$$= \log \omega_{nd} \tau; \ \tau = \frac{2\pi}{\omega_{nd}\sqrt{1 - \zeta^2}}$$

$$= \frac{2\pi\zeta}{\sqrt{1 - \zeta^2}} \simeq 2\pi\zeta$$

Natural Frequency - Damped System

$$\omega_{nd} = \omega_n\sqrt{1 - \zeta^2} = \frac{1}{2\pi}\sqrt{\frac{k}{m}(1 - \zeta)^2}$$

Logarithmic decrement - Structural or Solid Damping

$$\delta = \pi\gamma = \frac{\Delta\omega}{2\omega} \qquad \Delta w = \pi\gamma k X^2$$

c. Damped - Forced - Viscous Damping

Equation of Motion

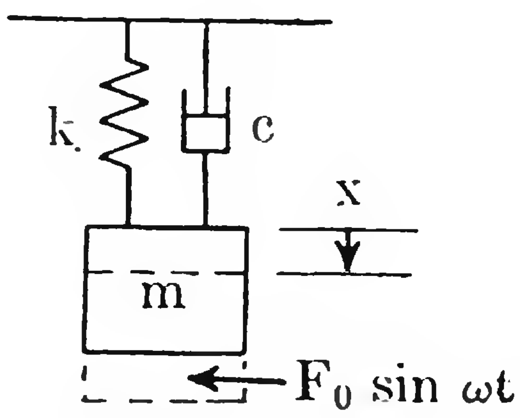


FIG. F

$$m\ddot{x} + c\dot{x} + kx = F_0 \sin \omega t$$

Magnification Factor

$$\frac{x}{x_0} = \frac{1}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_{nd}}\right)^2\right]^2 + \left(2\zeta \frac{\omega}{\omega_{nd}}\right)^2}} ; x_0 = \frac{F_0}{K} =$$ zero frequency deflection of the spring-mass system

$$\tan \phi = \frac{2\zeta \frac{\omega}{\omega_{nd}}}{1 - \left(\frac{\omega}{\omega_{nd}}\right)^2}$$

Amplitude at Resonance

$$x = \frac{F}{c\omega_{nd}} = \frac{x_0}{2\zeta}$$

Amplitude (oscillation starts at zero and builds up to $\frac{F_0 \cos \omega_n t}{c\omega_n}$)

$$x = \frac{F_0}{c\omega_n \sqrt{1 - \zeta^2}} e^{-\zeta\omega_n t} \sin\left(\sqrt{1 - \zeta^2}\,\omega_n t + \sin^{-1}\sqrt{1 - \zeta^2}\right) - \frac{F_0 \cos \omega_n t}{c\omega_n}$$

if $\omega = \omega_n$

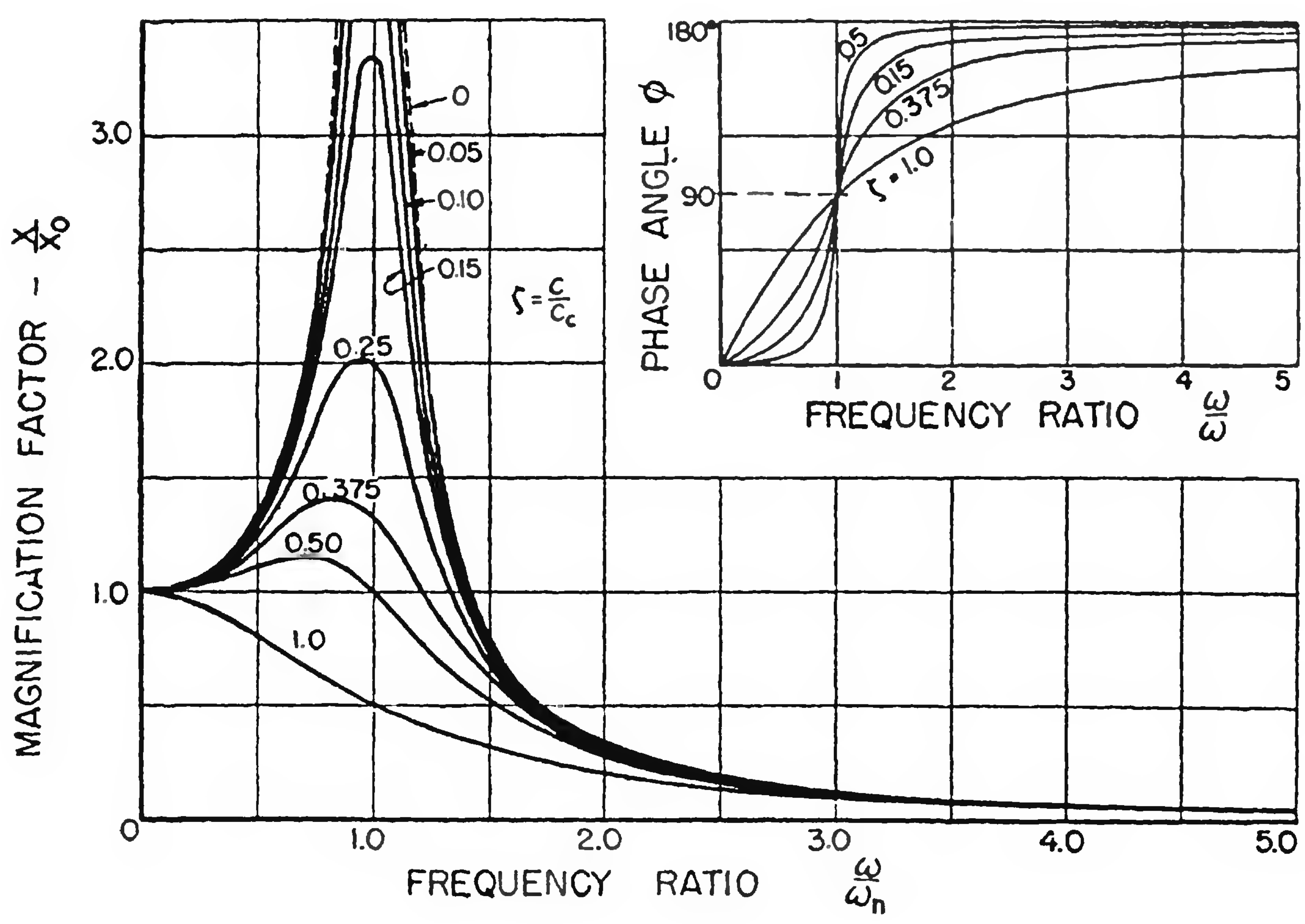
Eq. 4.20 Transmissibility

$$TR = \frac{F_{TR}}{F_0} = \frac{\sqrt{1 + \left(2\zeta \frac{\omega}{\omega_{nd}}\right)^2}}{\sqrt{\left[1 - \left(\frac{\omega}{\omega_{nd}}\right)^2\right]^2 + \left[2\zeta \frac{\omega}{\omega_{nd}}\right]^2}}$$

when damping is neglibible

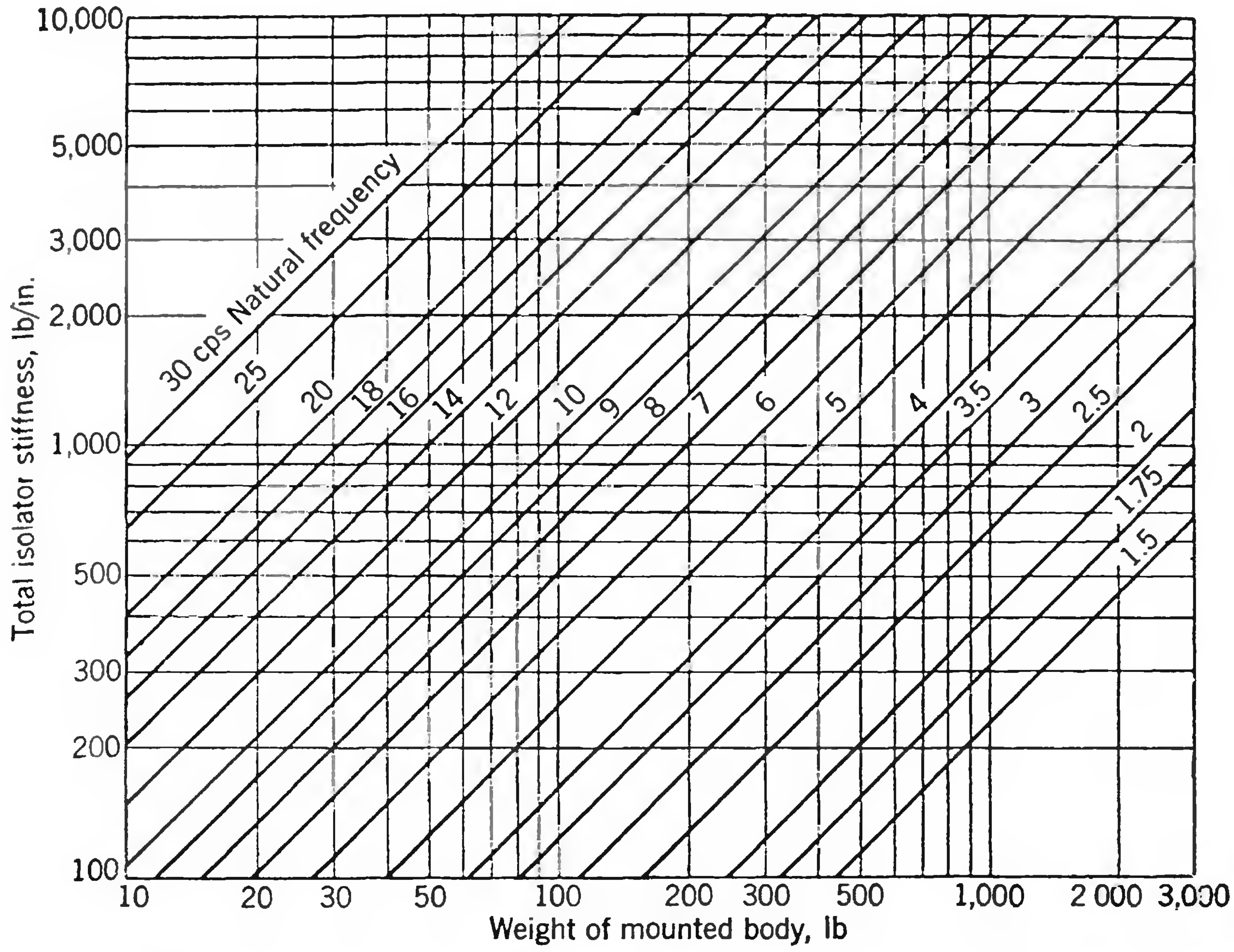
$$TR = \frac{1}{\left(\frac{\omega}{\omega_{nd}}\right)^2 - 1} \quad \text{and} \quad \frac{\omega}{\omega_{nd}} \geqslant \sqrt{2}$$

FIGURE 4.51B PLOT OF THE VIBRATION OF A VISCOUSLY DAMPED SYSTEM (Eq. 4.19c)*

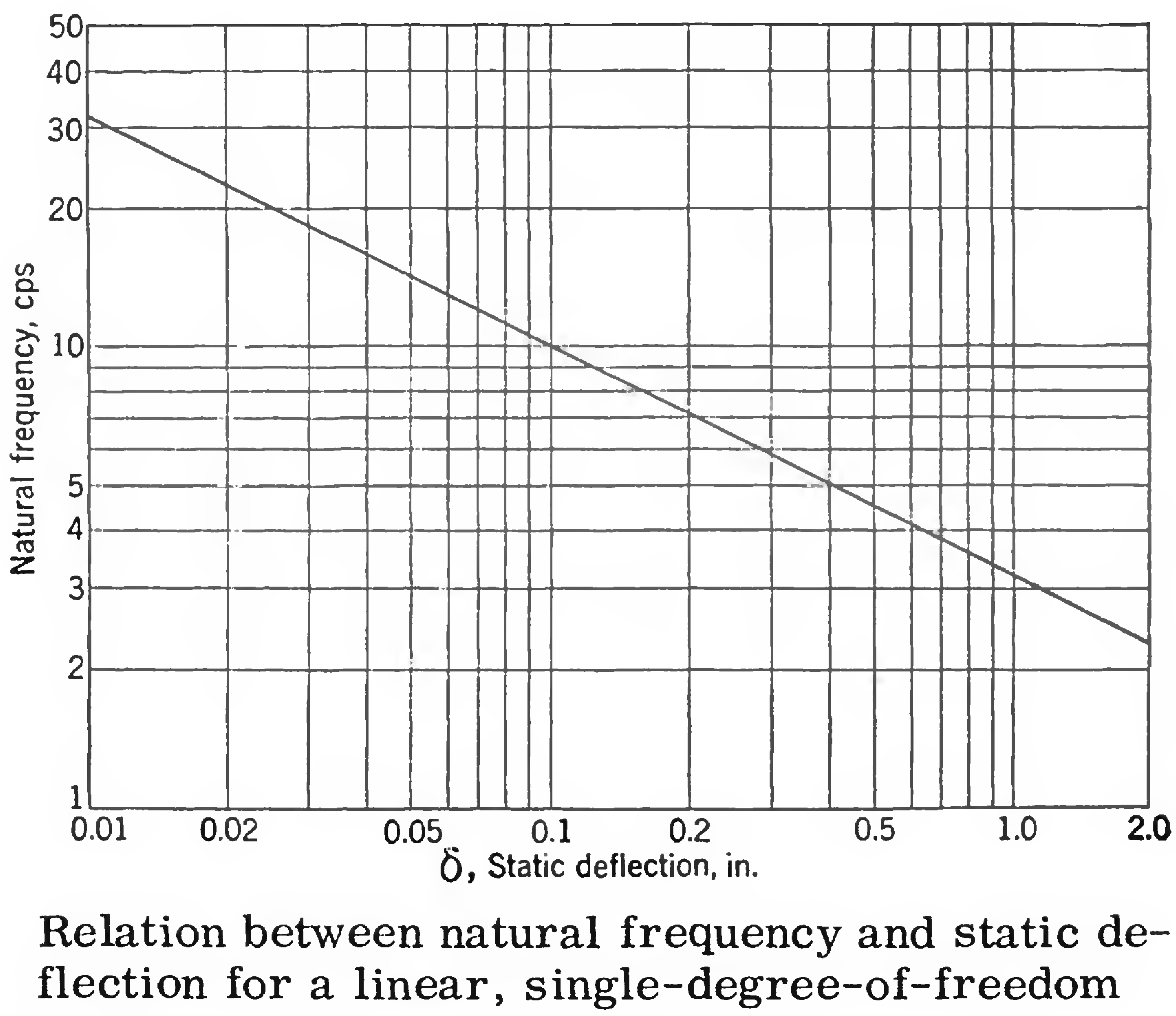


*From W. T. Thomson, "Mechanical Vibrations", 2nd Ed. Copyright 1953 by Prentice-Hall, Inc., Englewood Cliffs, N. J.

FIGURE 4.52 SINGLE DEGREE OF FREEDOM SYSTEM*



Natural frequency of a single-degree-of-freedom system as a function of weight of mounted body and total isolator stiffness.

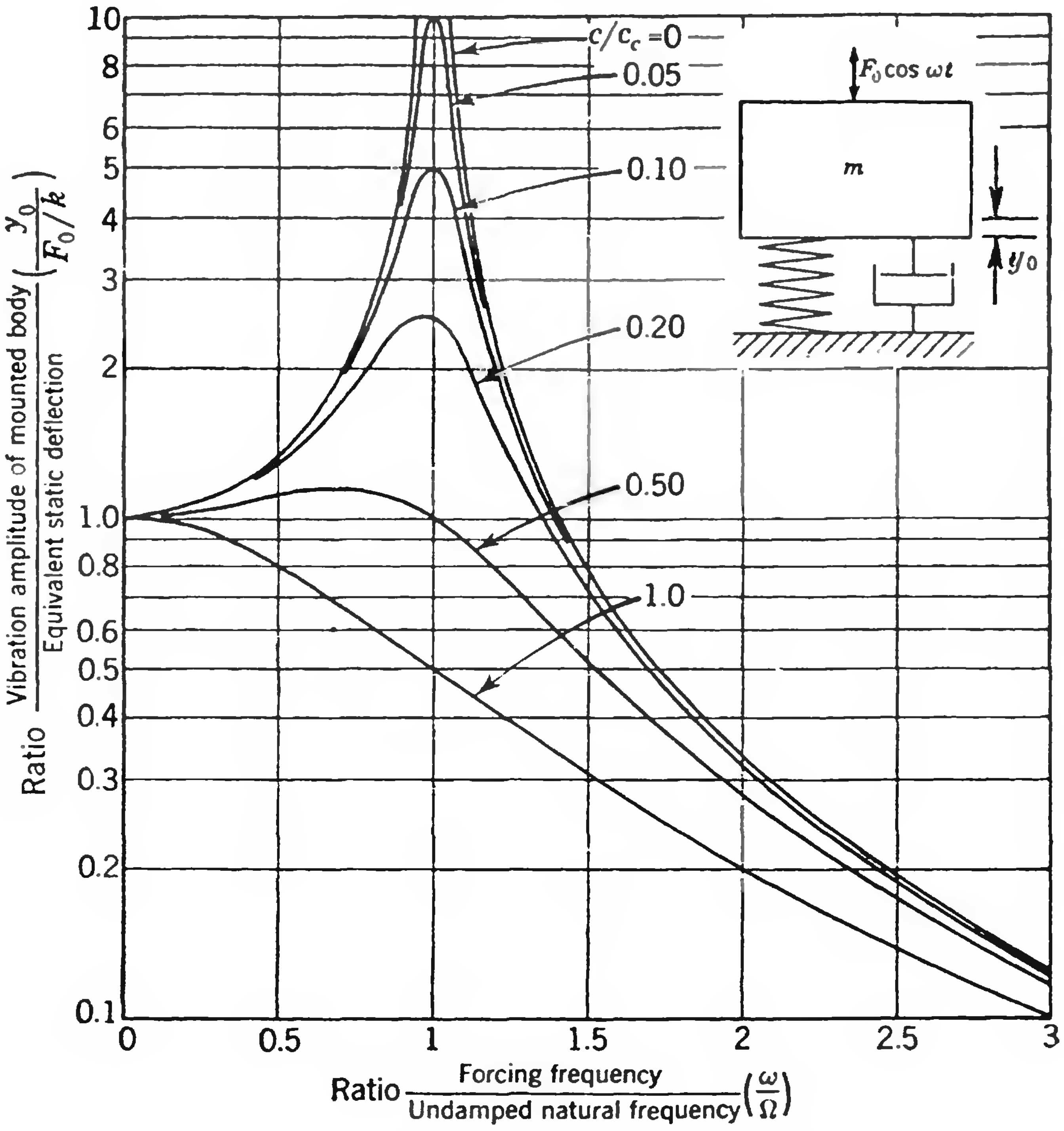


Relation between natural frequency and static deflection for a linear, single-degree-of-freedom system.

$$f = \frac{1}{2\pi}\sqrt{\frac{g}{\delta_{st}}}$$

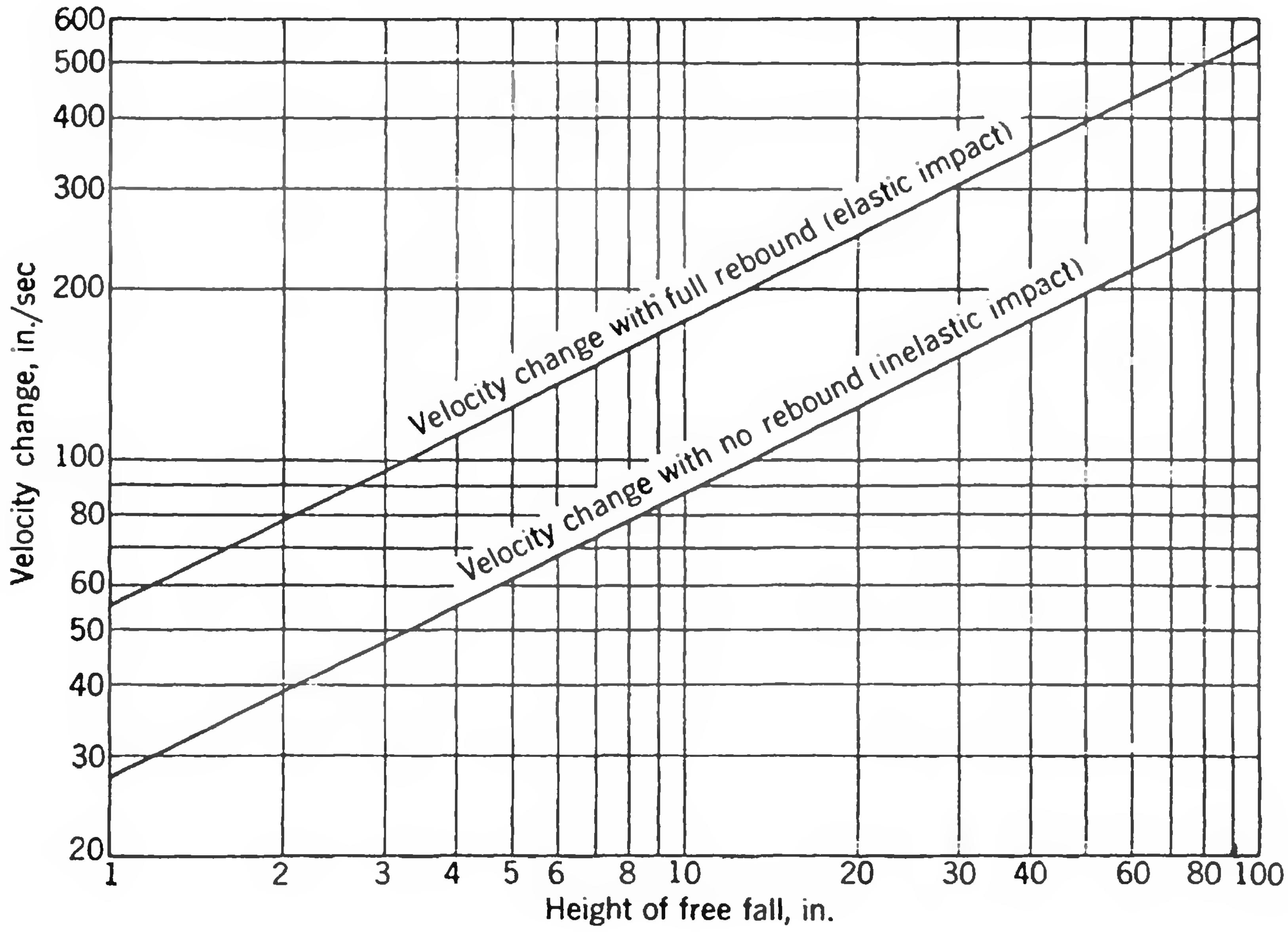
*Figs. 4.52–4.54 from C. E. Crede, "Vibration and Shock Isolation", 1951, Wiley, New York.

FIGURE 4.53 AMPLITUDE RATIO VS. FREQUENCY RATIO FOR DAMPED SINGLE DEGREE OF FREEDOM SYSTEM



Curves showing ratio of vibration amplitude to equivalent static deflection, as a function of the ratio of forcing to undamped natural frequencies. These curves apply to the viscously damped, single-degree-of-freedom system excited by the force $F_0 \cos \omega t$.

FIGURE 4.54 VELOCITY CHANGE RESULTING FROM ENGAGEMENT OF A FREELY FALLING BODY WITH A FIXED SUPPORT*



* Curves are included for perfectly elastic impact (full rebound) and perfectly inelastic impact (no rebound).

FIGURE 4.55(A) STRUCTURAL VIBRATION FORMULAS

Eq. 4.21 Structural Damping

Damping caused by structural impedance,

$$c = \frac{F}{e_F}\left(\frac{X_F}{X_o}\right)^2 = 2\frac{c}{c_c}$$

The damping is independent of the frequency and proportional to twice the amplitude.

Critical damping $c_c = 4\pi f M$

where $M = \frac{W}{386}$

Eq. 4.22 Structural Damping Ratios $\frac{c}{c_c} = \gamma$

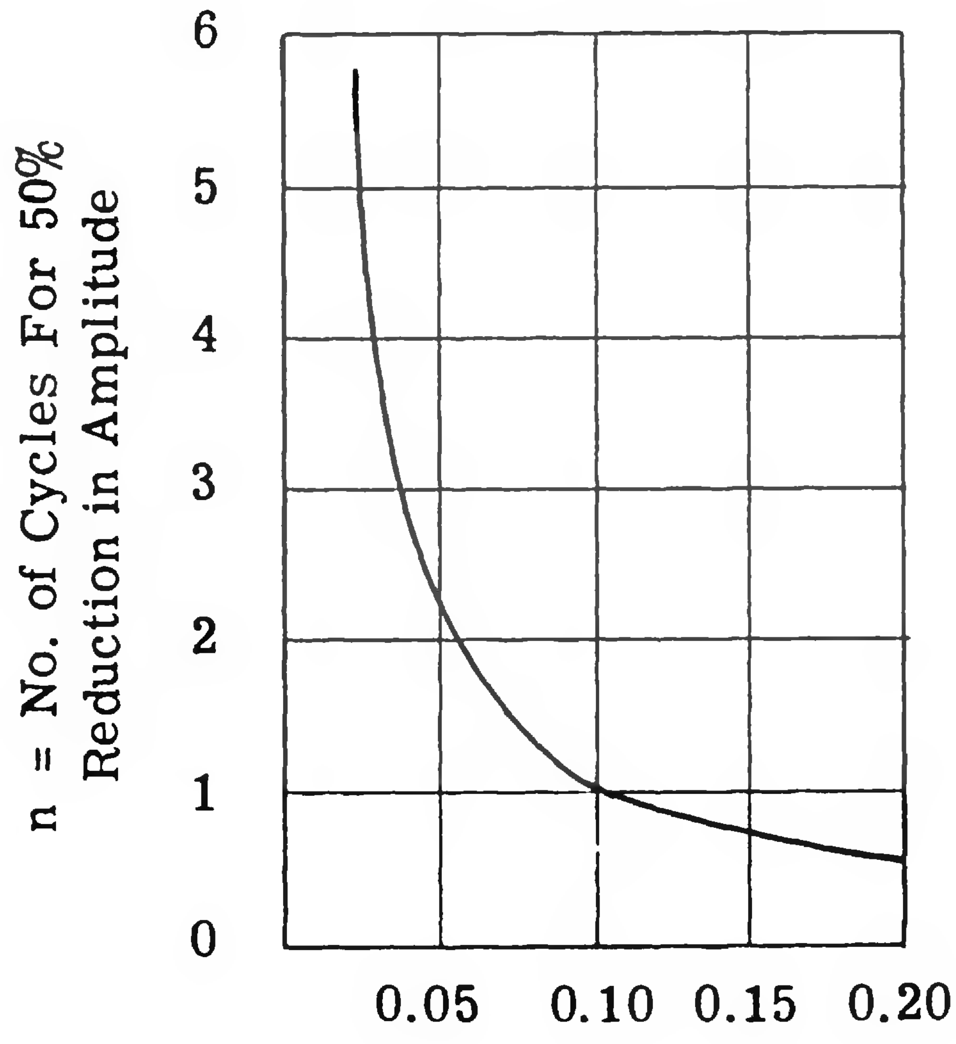
$$\frac{f_d}{f} = \sqrt{1-\left(\frac{c}{c_c}\right)^2}$$

Solid Beams	
Welded Frames	0.001 – 0.01
Bolted or Riveted Frames	0.005 – 0.05
Complex Riveted Structures	
Bending	0.005 – 0.04
Torsion	0.01 – 0.08
Masses on Rubber Springs	0.02 – 0.05

Eq. 4.23 Structural Amplification

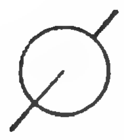
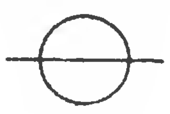
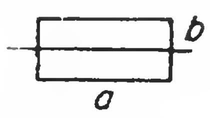
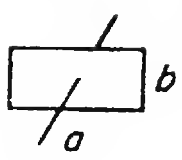
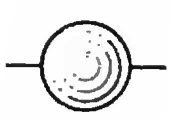
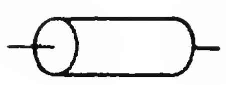
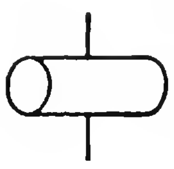
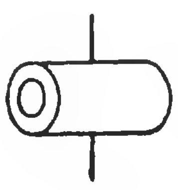
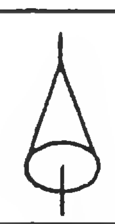
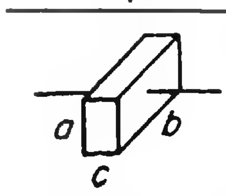
$$\text{Amp.} = \frac{1}{\text{structural damping}} = \frac{1}{2\frac{c}{c_c}}$$

FIGURE 4.55(B) DAMPING RATIO VS NUMBER OF CYCLES FOR 50% REDUCTION IN AMPLITUDE



γ, $\frac{c}{c_c}$ = Damping Ratio

FIGURE 4.56 (A) SOME MOMENTS OF INERTIA*

Description		Axis	Moment of inertia
	Circular plate Radius $= r$	Normal through center	$\dfrac{Mr^2}{2}$
	Circular plate Radius $= r$	Any diameter	$\dfrac{Mr^2}{4}$
	Rectangular plate Sides $= a, b$	Through center parallel to a	$\dfrac{Mb^2}{12}$
	Rectangular plate Sides $= a, b$	Through center perpendicular to plate	$\dfrac{M(a^2+b^2)}{12}$
	Sphere Radius $= r$	Any diameter	$\dfrac{2Mr^2}{5}\left(\text{where } M = \dfrac{\delta}{g}\dfrac{4}{3}\pi r^3\right)$
	Cylinder Length $= L$ Radius $= r$	Long axis	$\dfrac{Mr^2}{2}\left(\text{where } M = \dfrac{\delta}{g}\pi r^2 L\right)$
	Cylinder Length $= L$ Radius $= r$	Through center perpendicular to long axis	$M\left(\dfrac{r^2}{4}+\dfrac{L^2}{12}\right)$
	Hollow cylinder Length $= L$ Outside radius $= R$ Inside radius $= r$	Through center perpendicular to long axis	$\dfrac{M}{4}\left(R^2+r^2+\dfrac{L^2}{3}\right)$
	Hollow cylinder Length $= L$ Outside radius $= R$ Inside radius $= r$	Long axis	$\dfrac{M(R^2+r^2)}{2}$ $\left[\text{where } M = \dfrac{\delta}{g}\pi(R^2-r^2)L\right]$
	Right circular cone Radius of base $= r$ Altitude $= L$	Axis	$\dfrac{3}{10}Mr^2\left(\text{where } M = \dfrac{\delta}{g}\dfrac{\pi}{3}r^2L\right)$
	Right parallelo-piped Sides $= a, b, c$	Through center perpendicular to a face	$M\left(\dfrac{a^2+b^2}{12}\right)\left(\text{where } M = abc\dfrac{\delta}{g}\right)$

*Taken in part from *Hathaway Eng. News*, vol. 4, no. 2, p. 11, 1954.

M = mass = W/g
g = acceleration of gravity
W = weight
δ = specific weight of material

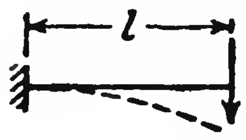
FIGURE 4.56(B) COLLECTION OF VIBRATION FORMULAS*

*Taken in part from J. P. Den Hartog, "Mechanical Vibrations", 3rd Ed. Copyright 1947, McGraw-Hill Book Company, Inc.

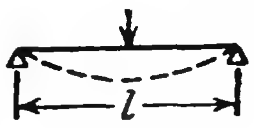
Eq. 4.24 Linear Spring Constants

("Load" per inch deflection)

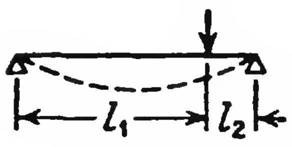
Coil dia. D; wire dia. d; n turns $\quad k = \dfrac{Gd^4}{8nD^3}$ (1)



Cantilever $\quad k = \dfrac{3EI}{l^3}$ (2)

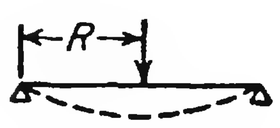


Beam on two supports; centrally loaded $\quad k = \dfrac{48EI}{l^3}$ (3)



Beam on two supports; load off center $\quad k = \dfrac{3EIl}{l_1^2 l_2^2}$ (4)

Clamped-clamped beam; centrally loaded $\quad k = \dfrac{192EI}{l^3}$ (5)

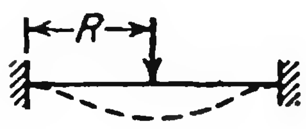


Circular plate, thickness t; centrally loaded; circumferential edge simply supported $\quad k = \dfrac{16\pi D}{R^2}\,\dfrac{1+\mu}{3+\mu}$ (6)

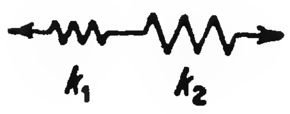
in which the plate constant is

$D = \dfrac{Et^3}{12(1-\mu^2)}$ (6a)

μ = Poisson's ratio ≈ 0.3



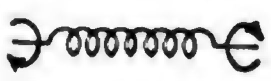
Circular plate; circumferential edge clamped $\quad k = \dfrac{16\pi D}{R^2}$ (7)



Two springs in series $\quad k = \dfrac{1}{1/k_1 + 1/k_2}$ (8)

Eq. 4.25 Rotational Spring Constants

("Load" per radian rotation)



Twist of coil spring; wire dia. d; coil dia. D; n turns $\quad k = \dfrac{Ed^4}{64nD}$ (9)

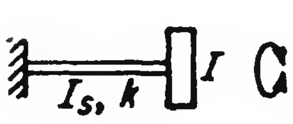
Bending of coil spring $\quad k = \dfrac{Ed^4}{32nD}\,\dfrac{1}{1+E/2G}$ (10)

Twist of hollow circular shaft, outer dia. D, inner dia. d, length l $\quad k = \dfrac{GI_p}{l} = \dfrac{\pi}{32}\,\dfrac{G(D^4-d^4)}{l}$ (11)

For steel $\quad k = 1.18 \times 10^6 \times \dfrac{D^4 - d^4}{l}$

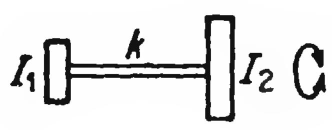
Eq. 4.26 Natural Frequencies of Simple Systems

End mass M; spring mass m, spring stiffness k $\quad \omega_n = \sqrt{k/(M + m/3)}$ (12)



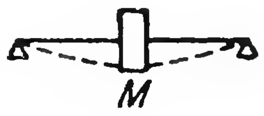
End inertia I; shaft inertia I_s, shaft stiffness k $\quad \omega_n = \sqrt{k/(I + I_s/3)}$ (13)

FIGURE 4.56(B) COLLECTION OF VIBRATION FORMULAS (cont.)

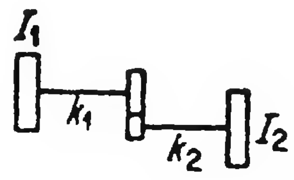


Two disks on a shaft $\quad \omega_n = \sqrt{\dfrac{k(I_1 + I_2)}{I_1 I_2}}$ (14)

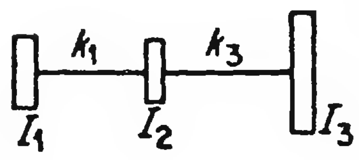
Cantilever; end mass M; beam mass m, stiffness by formula (2) $\quad \omega_n = \sqrt{\dfrac{k}{M + 0.23m}}$ (15)



Simply supported beam; central mass M; beam mass m; stiffness by formula (3) $\quad \omega_n = \sqrt{\dfrac{k}{M + 0.5m}}$ (16)



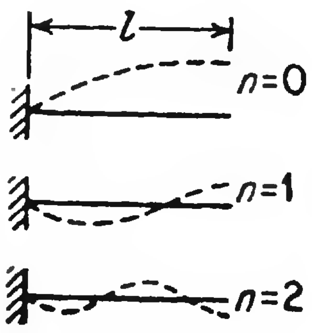
Massless gears, speed of I_2 n times as large as speed of I_1 $\quad \omega_n = \sqrt{\dfrac{1}{\dfrac{1}{k_1} + \dfrac{1}{n^2 k_2}} \times \dfrac{I_1 + n^2 I_2}{I_1 \cdot n^2 I_2}}$ (17)



$$\omega_n^2 = \frac{1}{2}\left(\frac{k_1}{I_1} + \frac{k_3}{I_3} + \frac{k_1 + k_3}{I_2}\right) \pm$$
$$\pm \frac{1}{2}\sqrt{\left(\frac{k_1}{I_1} + \frac{k_3}{I_3} + \frac{k_1 + k_3}{I_2}\right)^2 - 4\,\frac{k_1 k_3}{I_1 I_2 I_3}\,(I_1 + I_2 + I_3)} \qquad (18)$$

Eq. 4.27 Longitudinal and Torsional Vibration

(Longitudinal and torsional vibration)



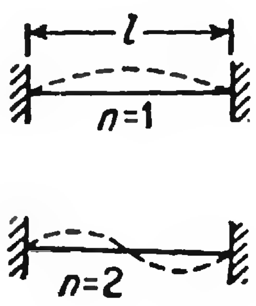
Longitudinal vibration of cantilever: A = cross section, E = modulus of elasticity. μ_1 = mass per unit length, $n = 0,1,2,3$ = number of nodes

$$\omega_n = \left(n + \frac{1}{2}\right)\pi\sqrt{\frac{AE}{\mu_1 l^2}} \qquad (19)$$

For steel and l in inches this becomes

$$f = \frac{\omega_n}{2\pi} = (1 + 2n)\,\frac{51{,}000}{l} \qquad (19a)$$

cycles per second

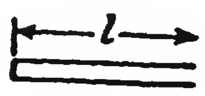


Longitudinal vibration of beam clamped (or free) at both ends

$$\omega_n = n\pi\sqrt{\frac{AE}{\pi_1 l^2}} \qquad (19b)$$

For steel, l in inches

$$f = \frac{\omega_n}{2\pi} = \frac{102{,}000}{l} \text{ cycles/sec.} \qquad (20a)$$

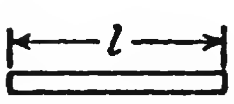


Organ pipe open at one end, closed at the other

For air at 60°F., l in inches:

$$f = \frac{\omega_n}{2\pi} = (1 + 2n)\,\frac{3{,}300}{l} \qquad (20b)$$

cycles/sec.



Organ pipe closed (or open) at both ends (air at 60°F.)

$$f = \frac{n6{,}600}{l} \text{ cycles/sec.} \qquad (21)$$

Torsional vibration of beams

Same as (19) and (20); replace tensional stiffness AE by torsional stiffness C ($= GI_p$ for circular cross section); replace μ_1 by the moment of inertia per unit length $i = \dfrac{I_{\text{bar}}}{l}$

Eq. 4.28 Lateral Vibrations

$$\omega = n^2 \sqrt{\frac{gEI}{w}} \cdot$$

where the number n depends on the boundary conditions of the problem. The following table lists numerical values of $(nl)^2$ for typical end conditions.

Beam configuration	$(n_1l)^2$ Fundamental	$(n_2l)^2$ Second Mode	$(n_3l)^2$ Third Mode
Simply supported	9.87	39.5	88.9
Cantilever	3.52	22.4	61.7
Free-free	22.4	61.7	121.0
Clamped-clamped	22.4	61.7	121.0
Clamped-hinged	15.4	50.0	104.0
Hinged-free	0	15.4	50.0

Eq. 4.29 Margin of Safety

$$MS = \frac{\text{Allowable Load}}{\text{Actual Load}} - 1 = \frac{\text{Allowable Stress}}{\text{Actual Stress}} - 1$$

FIGURE 4.57 ACCELERATION CHART

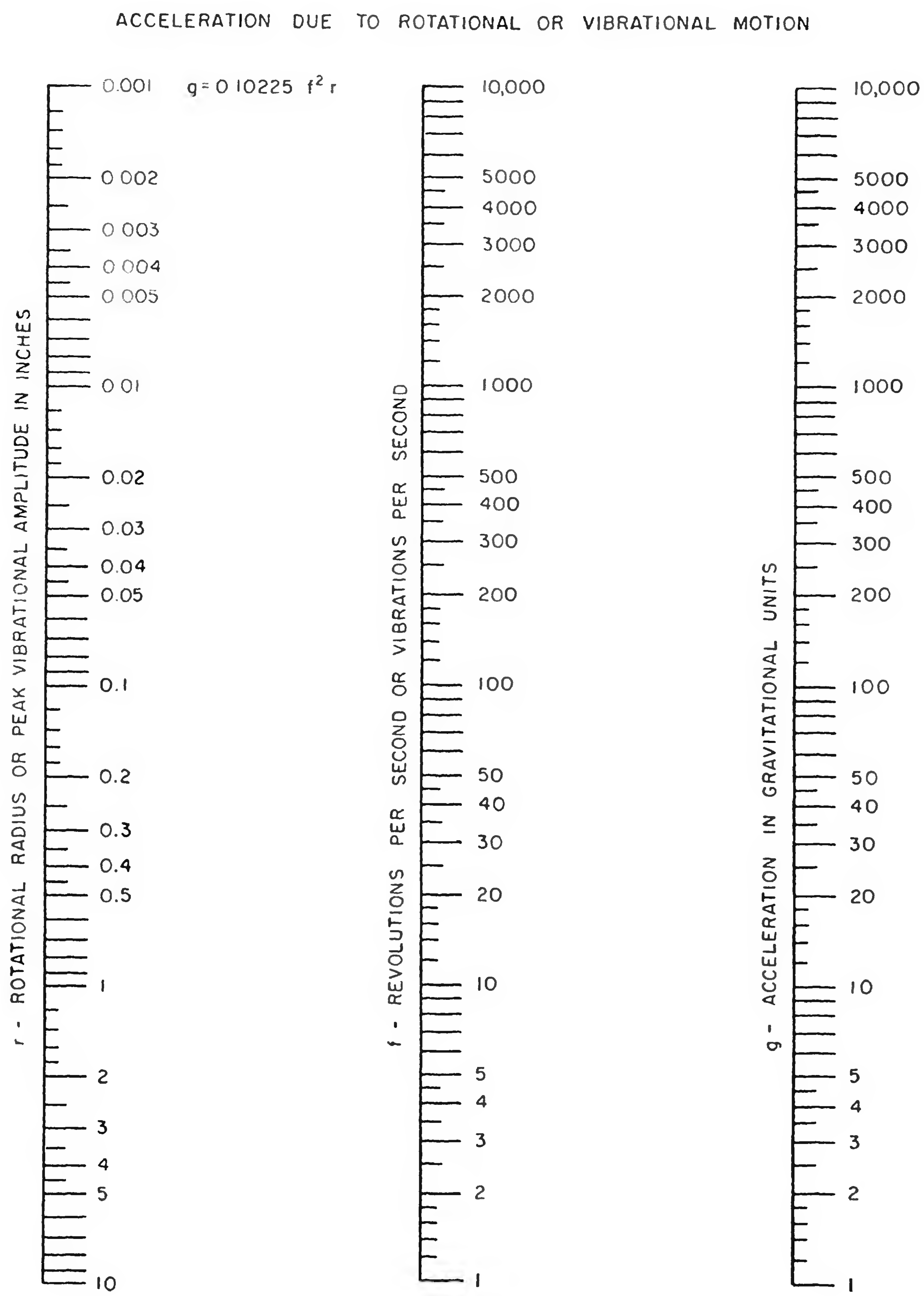


FIGURE 4.58 VIBRATION ISOLATION EFFICIENCY CURVES

For simple linear vibration, the curves give the percentage of vibration isolation it is possible to obtain in a flexibly mounted assembly with any combination of static deflection and disturbing frequencies. The area lower shaded shows the region of magnification of vibration that occurs when the ratio of the disturbing frequency to the natural frequency of the mounted assembly is less than $\sqrt{2}$. A condition of resonance exists when the natural frequency of the assembly and the disturbing frequency are equal. The upper shaded area shows the percentage of the vibratory forces prevented from reaching the supporting structure when flexible mountings are used. Reduction in the transfer of vibratory forces is obtained only when the ratio of the disturbing frequency to the natural frequency is greater than $\sqrt{2}$.

The term decibel as used on this chart is mathematically expressed by the equation

$$\text{Decibels} = 20 \text{ Log}_{10} \frac{A}{A}$$

where A is the amplitude of the mounted mass and A represents the amplitude of the disturbing frequency.

Data Courtesy: Lord Mfg. Co., Erie, Pa.

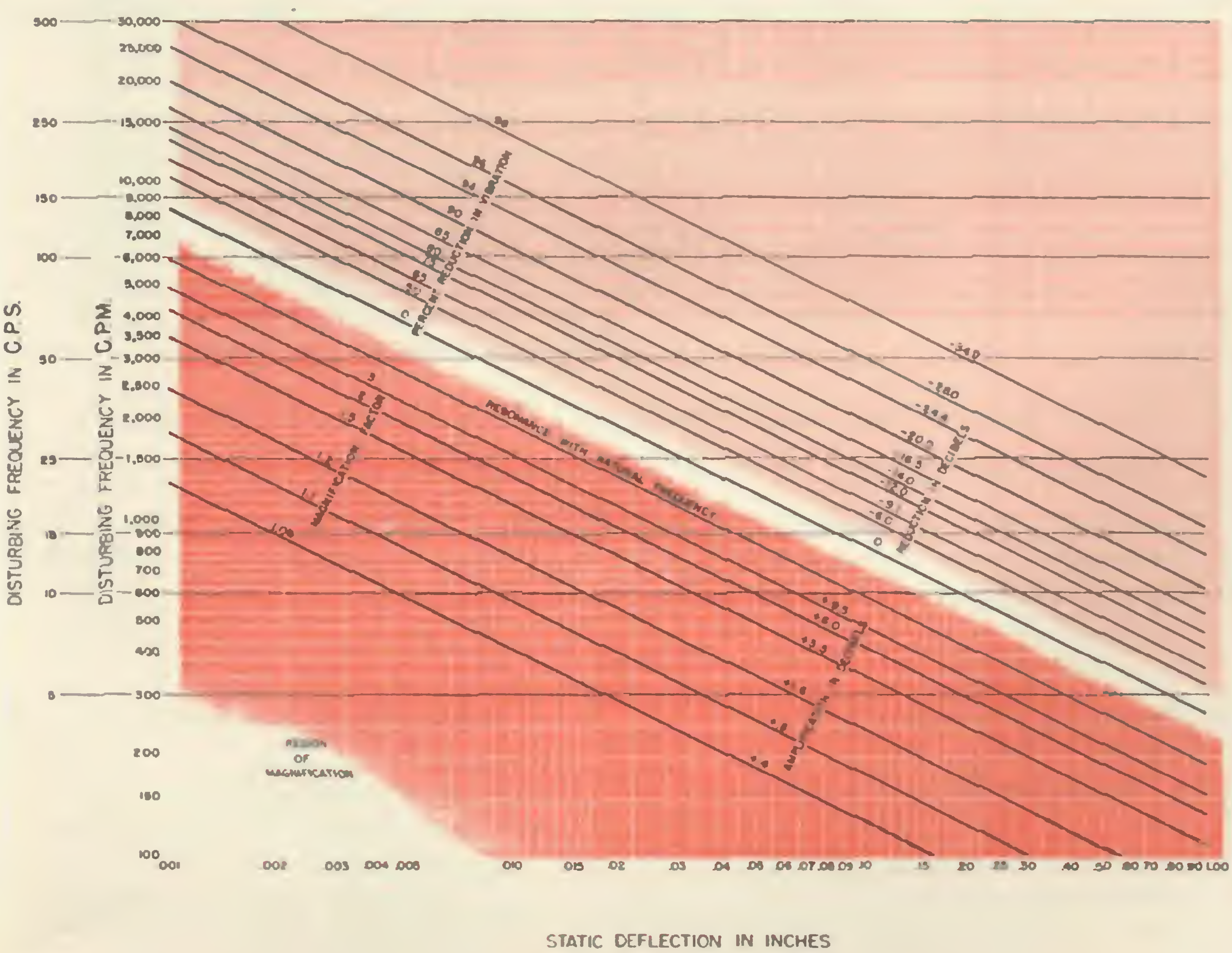
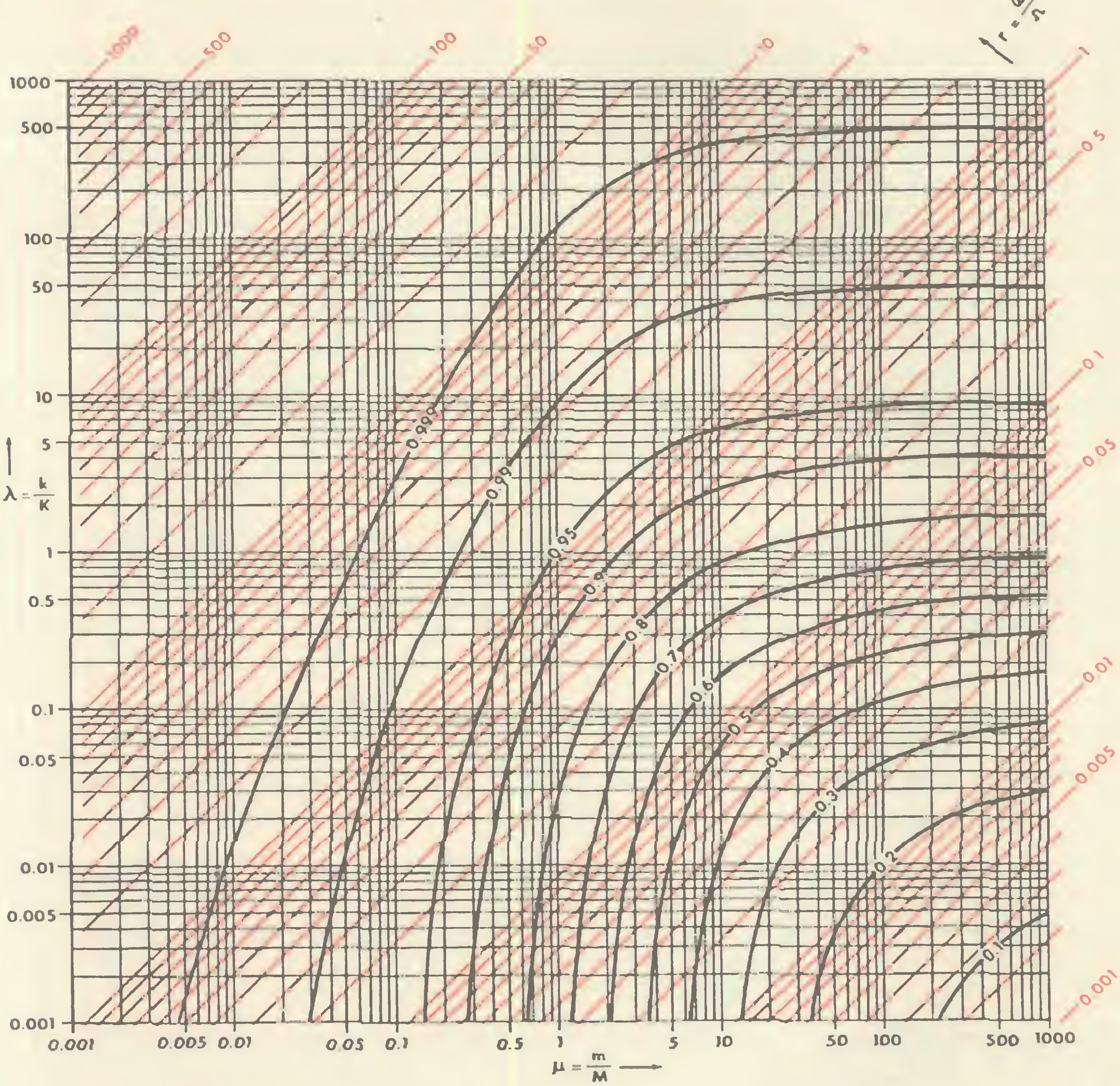


FIGURE 4.59 VELOCITY-SHOCK DIAGRAMS FOR TWO-DEGREE VIBRATION SYSTEMS

Figure 4.59(A) Contour Chart of Mount Deflection Factor D



1. Given a piece of equipment, what should be the mount characteristics?
2. Given the mount, what should be the equipment characteristics?

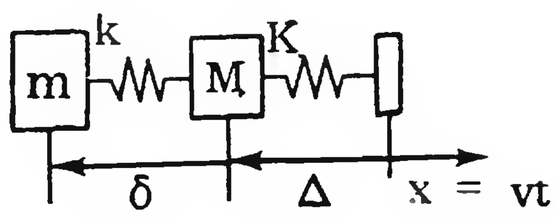
The charts apply to systems with two degrees of fredom when the base is given a step velocity, V. The system (k, m) is the equipment or element to be protected while the system (K, M) is the cushioning mount.

Nomenclature

D = mount deflection correction factor
g = acceleration of gravity (386 in. sec.$^{-2}$)
k = equipment or element spring constant (lb. in.$^{-1}$)
K = mount spring constant (lb. in.$^{-1}$)
L = load factor ratio
m = equipment or element mass (lb. sec.^{2} in.$^{-1}$))
M = mount mass (lb. sec.^{2} in.$^{-1}$)
n = load factor for mass m (number of g's)
r = frequency ratio of equipment to mount
t = time (sec.)

FIGURE 4.59 VELOCITY-SHOCK DIAGRAMS FOR TWO-DEGREE VIBRATION SYSTEMS (cont)

T = shock transmissibility
V = step velocity on base (in sec.$^{-1}$)
X = absolute motion of base (in.)
δ = maximum deflection of spring k (in.)
Δ = maximum deflection of spring K (in.)
λ = stiffness ratio of equipment to mount
μ = mass ratio of equipment to mount
ω = uncoupled equipment frequency (rad. sec.$^{-1}$)
Ω = uncoupled mount frequency (rad. sec.$^{-1}$)
cps = cycles per second
lb = pounds force
rad = radians
sec = seconds



Eq. 4.29

$$\delta = \frac{V}{\omega} T \qquad \Delta = D \frac{V}{\Omega} \sqrt{1 + \frac{m}{M}}$$

$$n = \frac{V\omega}{g} T = \frac{V\Omega}{g} L$$

$$\omega = \sqrt{\frac{k}{m}} \qquad \Omega = \sqrt{\frac{K}{M}}$$

Values of T, D, and L may be read directly from the charts using any two of the three variables:

$$\lambda = \frac{k}{K} \qquad \mu = \frac{m}{M} \qquad r = \frac{\omega}{\Omega} = \sqrt{\frac{\lambda}{\mu}}$$

The chart for T is particularly useful where the equipment characteristics are fixed and a mount must be selected to reduce the shock transmissibility. On the other hand, the chart for L is convenient where the mount characteristics are fixed and the equipment must be selected to survive the shock loads.

In cases beyond the range of the charts or where higher accuracy is needed, the functions may be computed from the formulas:

$$D = \frac{r(1 + r) + \lambda}{\sqrt{r^2 + \lambda}\ \sqrt{(r + 1)^2 + \lambda}}$$

$$L = \frac{r}{\sqrt{(r - 1)^2 + \lambda}}$$

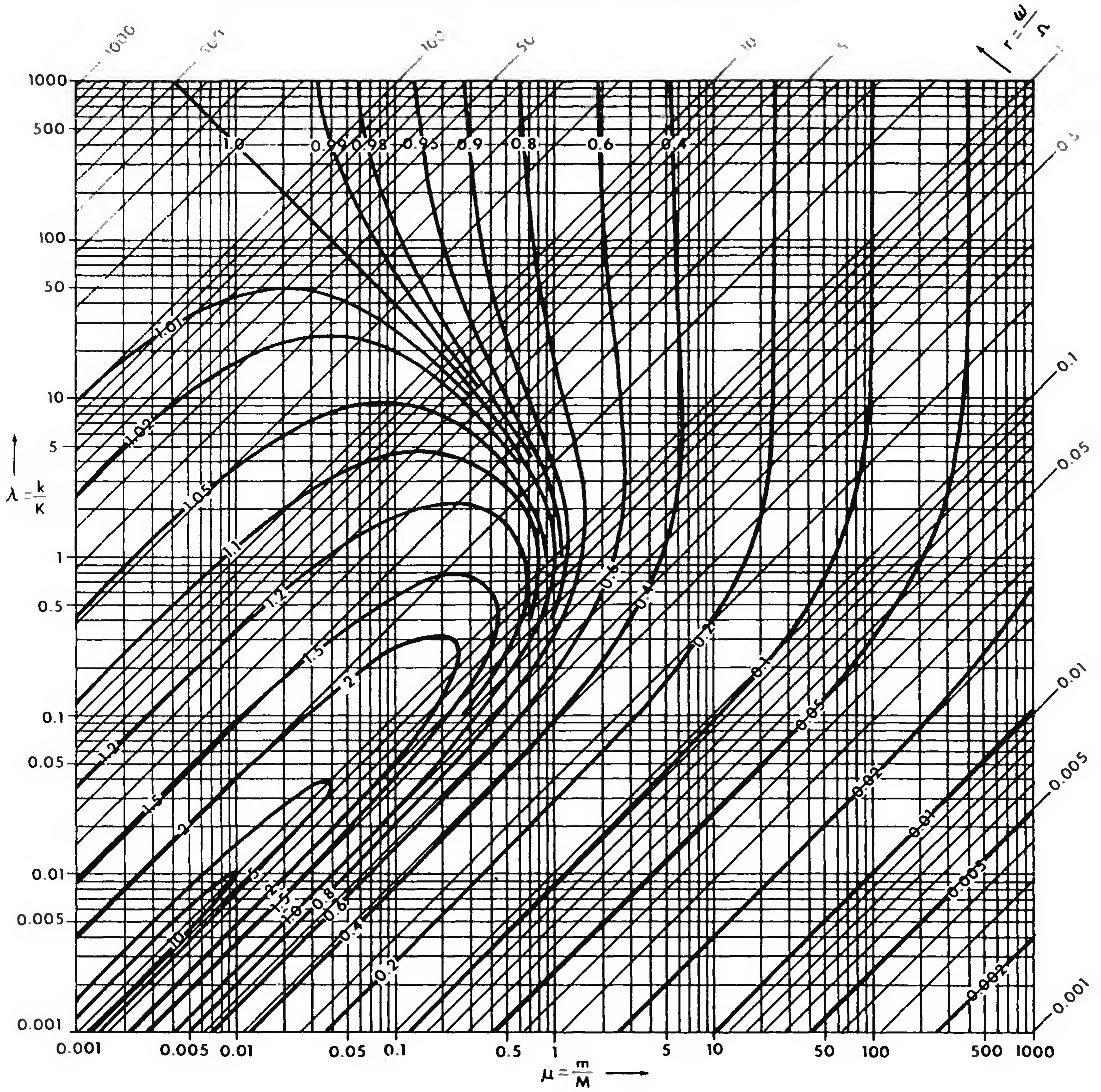
$$T = \frac{1}{\sqrt{(r - 1)^2 + \lambda}}$$

Numerical Example

g = 386.1 in. sec.$^{-2}$
k = 1500 lb. in.$^{-1}$
K = 500 lb. in.$^{-1}$
m = 4.00 lb. mass = 0.0104 lb. sec.^{2} in.$^{-1}$
M = 10.00 lb. mass = 0.0259 lb. sec.^{2} in.$^{-1}$
V = 20.0 in. sec.$^{-1}$

FIGURE 4.59 VELOCITY-SHOCK DIAGRAMS FOR TWO-DEGREE VIBRATION SYSTEMS (cont.)

Figure 4.59(B) Contour Chart of Load Factor Ratio L



$$\omega = \sqrt{\frac{k}{m}} = 380 \text{ rad. sec.}^{-1} = 60.5 \text{ cps.}$$

$$\Omega = \sqrt{\frac{K}{M}} = 139 \text{ rad. sec.}^{-1} = 22.1 \text{ cps.}$$

$$\lambda = \frac{k}{K} = 3.00 \qquad \mu = \frac{m}{M} = 0.400 \qquad r = \frac{\omega}{\Omega} = 2.73$$

$$\frac{V}{\omega} = 0.0525 \text{ in.} \qquad \frac{V}{\Omega} = \sqrt{1 + \frac{m}{M}} = 0.170$$

$$\frac{V\omega}{g} = 19.7 \qquad \frac{V\Omega}{g} = 7.20$$

Using any two of the three coordinates; λ, μ, and r, the values read from the charts are:

$$T = 0.41 \qquad D = 0.99 \qquad L = 1.12$$

so that

$$\delta = \frac{V}{\omega} T = 0.022 \text{ in.} \quad \Delta = D \frac{V}{\Omega} \sqrt{1 + \frac{m}{M}} = 0.17 \text{ in.}$$

$$n = \frac{V\omega}{g} T = \frac{V\Omega}{g} L = 8.1 \text{ (g's)}$$

Acknowledgment:
Two of these charts are taken from R.B. McCalley's paper entitled: "Velocity Shock Transmission in Two Degree Series Mechanical Systems" which appeared in Supplement to Shock and Vibration Bulletin No. 23 (unclassified), published by the Office of the Secretary of Defense, Research and Development, Washington, D. C., June, 1956. The original paper contains the mathematical derivations which are too lengthy to include here.

Figure 4.59(C) Contour Chart of Shock Transmissibility T

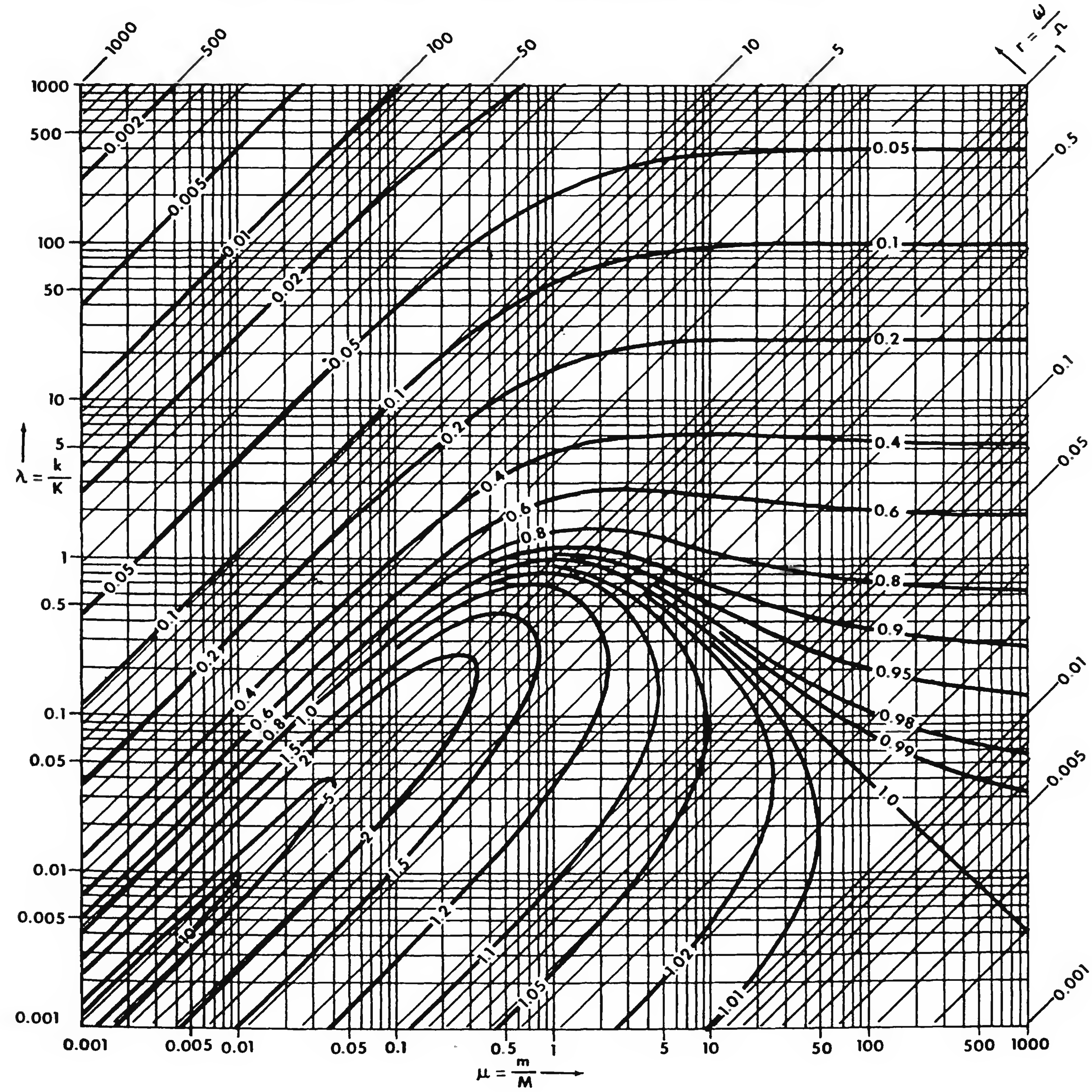


FIGURE 4.60 VIBRATION DESIGN CHARTS

Beams and plates are structural elements common to all mechanical designs. It is frequently necessary to so design these elements that they have either a selected natural frequency or so that their natural frequencies are sufficiently far removed from excitation frequencies to avoid resonance.

The theory underlying the data given for the natural frequencies of beams and plates assumes small deflections and neglects rotary inertia and shear effects. These restrictions must be kept in mind when determining frequencies from the charts.

Method

The method is based on the use of a frequency constant defined as

Eq. 4.30

Equation	Structure	Nomenclature
$C = fL^2/r$	Beams	f = natural frequency, cps L = beam length or span length, in. r = radius of gyration = $\sqrt{(I/A)}$ in.
$C = fa^2/h$	Square and rectangular plates	a = length of plate side, in. h = plate thickness, in.
$C = fr^2/h$	Circular plates	r = radius of the plate, in. h = thickness of the plate, in.

Fig. 4.60 A-L, inclusive, give the values of the frequency constant C for various structures of engineering interest for the different modes of vibration. These tabulated values of C are based on the characteristic density and Young's modulus for steel. Fig. 4.60(M) is a tabulation of the correction factor which must be used for nonsteel structures.

The nomograph, Fig. 4.60(N), may be used with the proper frequency constant C and the characteristic dimensions to determine the natural frequency directly. Nomographs, Figs. 4.60(O) and 4.60(P), present an alternate method of determining the natural frequency by first determining the value of L^2/r from the nomograph, Fig. 4.60(O), and then entering nomograph, Fig. 4.60(P), with this item and the frequency constant. A third method is presented in Fig. 4.60(Q), which is a chart presentation of the variation of frequency with the frequency constant and the ratio L^2/r. Figs. 4.60(N) through 4.60(Q) are to be used with Figs. 4.60(A) through 4.60(F) in which the frequency constants are tabulated.

For materials other than steel, the material correction factor K_m is obtained from Fig. 4.60(M). With this factor, and the natural frequency of a steel member of the same dimensions f_s, the nomograph, Fig. 4.60(R) may be used to determine the natural frequency.

Some of the less common structural members, such as membranes, have a frequency relation which is not defined by the foregoing equations. In such cases, numerical or slide-rule calculation is necessary. The frequency constants for these members are given in Fig. 4.60(G) thru (L).

FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Example

Determine the fundamental natural frequency of a titanium circular plate, Ti-75A, 3-in radius and 0.090 in. thick. The plate is fixed at the center. The estimated temperature of operation is 400 F.

1. From Fig. 4.60(F)

$$C/10^4 = 3.649$$

2. From Fig. 4.60(N), the natural frequency of a steel plate of these dimensions is

$$f_s = 390 \text{ cps}$$

3. Or, from Fig. 4.60(O), with $r = 3$ and $h = 0.09$, $r^2/h = 100$

4. And, from Fig. 4.60(P) or Fig. 4.60(Q), the natural frequency of a steel plate of these dimensions is

$$f_s = 360 \text{ cps}$$

5. From Fig. 4.60(M), the material correction factor for Ti-75A at 400 F is

$$K_m = 0.910$$

6. With this value of K_m and the frequency of step 2 or 4, the frequency for the titanium plate is determined from Fig. 4.60(R) as

$$f = 325 - 350 \text{ cps}$$

FIGURE 4.60(A) Frequency Constant $C = fL^2/r$ for Uniform Steel Beams

f • NATURAL FREQUENCY, cps   L • BEAM LENGTH, inches   r • RADIUS OF GYRATION $\sqrt{I/A}$

$$C/10^4 = (fL^2/r)/10^4$$

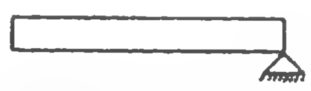
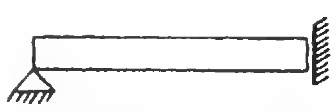
BEAMS	MODE NUMBER				
	1	2	3	4	5
 CLAMPED - CLAMPED  FREE - FREE	71.95	198.29	388.73	642.60	959.94
 CLAMPED - FREE	11.30	70.85	198.30	388.73	642.60
 CLAMPED - HINGED  FREE - HINGED	49.57	160.65	335.17	573.20	874.65
 CLAMPED - GUIDED  FREE - GUIDED	17.98	97.18	239.98	446.25	715.98
 HINGED - HINGED  GUIDED - GUIDED	31.73	126.93	285.60	507.73	793.33
 HINGED - GUIDED	7.93	71.40	198.33	388.73	642.60

FIGURE 4.60 VIBRATION DESIGN CHARTS(cont.)

Figure 4.60(B) Frequency Constant $C = fL^2/r$ for Variable Section Steel Beams

f = NATURAL FREQUENCY, cps
L = BEAM LENGTH, inches
r = RADIUS OF GYRATION = $\sqrt{I/A}$ inches

$C/10^4 = (fL^2/r)/10^4$

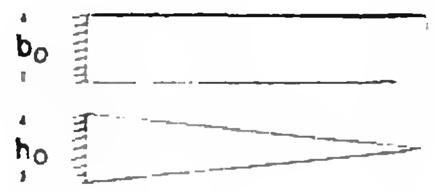
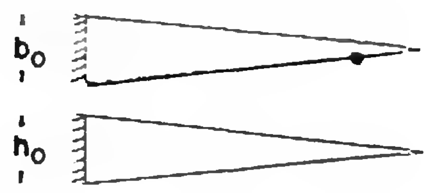
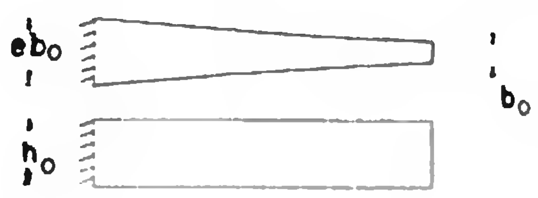
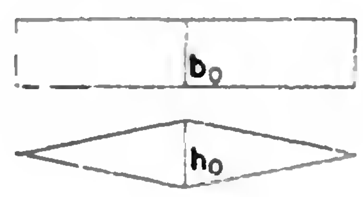
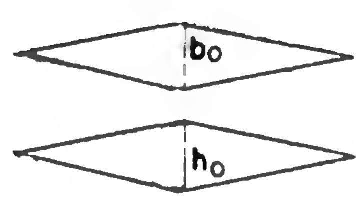
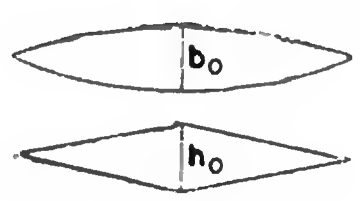
VARIABLE SECTION BEAMS	b/b_0	h/h_0	MODE 1	MODE 2	MODE 3
	1	x/L	17.09	48.89	96.57
	x/L	x/L	26.08	68.08	123.64
	$(x/L)^{1/2}$	x/L	22.30	58.18	109.90
	$e^{x/L}$	1	15.23	77.78	206.07
	1	x/L	21.21 35.05	56.97	SYMMETRIC ANTISYMMETRIC
	x/L	x/L	32.73 49.50	76.57	SYMMETRIC ANTISYMMETRIC
	$(x/L)^{1/2}$	x/L	25.66 42.02	66.06	SYMMETRIC ANTISYMMETRIC

FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(C) Frequency Constant $C = fa^2/h$ for Square Steel Plates

f = NATURAL FREQUENCY, cps
a = SIDE OF PLATE, inches
h = PLATE THICKNESS, inches

F = FREE
S = SUPPORTED
C = CLAMPED

$C/10^4 = (fa^2/h)/10^4$

SQUARE PLATES	MODE NUMBERS					
	1	2	3	4	5	6
F (top), F (left), F (right), C (bottom)	3.40	8.32	20.86	26.71	30.32	
F (top), C (left), F (right), C (bottom)	6.77	23.43	26.07	46.75	61.44	
F (top), F (left), F (right), F (bottom)	13.72	19.99	23.26	34.98	59.93	63.47
S (top), S (left), S (right), S (bottom)	19.20	48.00	76.82	96.01	124.82	163.25
S (top), S (left), S (right), C (bottom)	23.01	50.28	57.06	83.79	97.58	110.13
S (top), C (left), C (right), S (bottom)	28.16	53.26	67.44	92.02	99.43	125.60
C (top), C (left), C (right), C (bottom)	35.01	71.42	105.36	128.03	128.71	160.72

FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(D) Frequency Constant $C = fa^2/h$ for Rectangular Steel Plates

f = NATURAL FREQUENCY, cps
a = SIDE OF PLATE, inches
h = PLATE THICKNESS, inches

F = FREE
S = SUPPORTED
C = CLAMPED

$C/10^4 = (fa^2/h)/10^4$

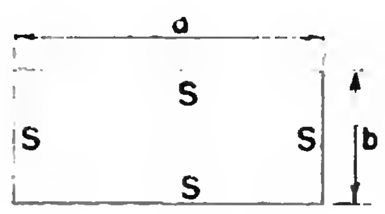
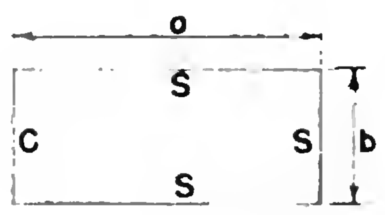
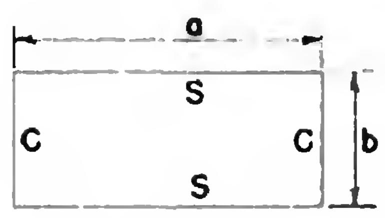
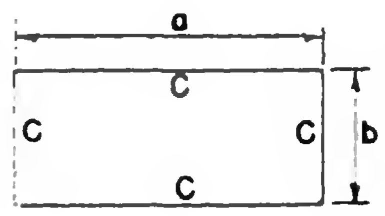
RECTANGULAR PLATES	FIRST MODE						
	b/a	1.0	1.5	2.0	2.5	3.0	INFINITE
	$C/10^4$	19.20	13.87	12.00	11.14	10.67	9.60
	b/a	1.0	1.5	2.0	2.5	3.0	INFINITE
	$C/10^4$	23.01	18.39	16.86	16.18	15.82	15.01
	a/b	1.0	1.5	2.0	2.5	3.0	INFINITE
	$C/10^4$	23.01	15.15	12.57	11.43	10.84	9.60
	b/a	1.0	1.5	2.0	2.5	3.0	INFINITE
	$C/10^4$	28.16	24.37	23.17	22.64	22.37	21.76
	a/b	1.0	1.5	2.0	2.5	3.0	INFINITE
	$C/10^4$	28.16	16.90	13.32	11.80	11.05	9.60
	b/a	1.0	1.5	2.0	2.5	3.0	INFINITE
	$C/10^4$	35.00	26.27	23.90	23.12	22.56	21.76

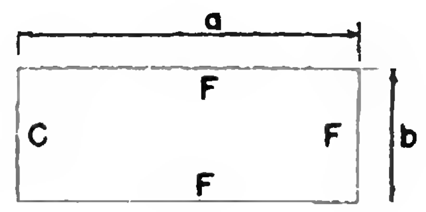
FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(E) Frequency Constant $C = fa^2/h$ for Cantilever Steel Plates

f = NATURAL FREQUENCY, cps
a = SIDE OF PLATE, inches
h = PLATE THICKNESS, inches

F = FREE
C = CLAMPED

$C/10^4 = (fa^2/h)/10^4$

RECTANGULAR CANTILEVER PLATE	a/b	MODE NUMBER 1	2	3	4	5
	1/2	3.41	5.23	21.36	9.98	24.18
	1	3.40	8.32	20.86	26.71	30.32
	2	3.38	14.52	21.02	91.92	47.39
	5	3.36	33.79	20.94	548.60	103.03

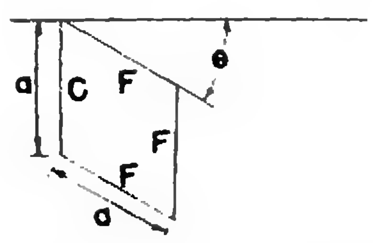
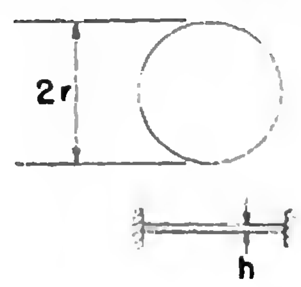
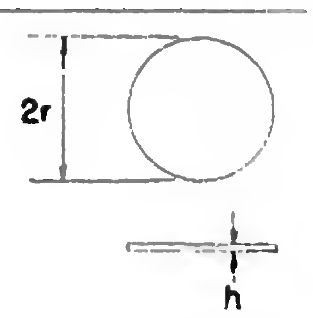
SKEWED CANTILEVER PLATE	SKEW ANGLE θ DEGREES	MODE NUMBER 1	2	3	4	5
	15°	3.50	8.63			
	30°	3.85	9.91			
	45°	4.69	13.38			

Figure 4.60(F) Frequency Constant $C = fr^2/h$ for Circular Steel Plates

f = NATURAL FREQUENCY, cps
h = THICKNESS OF PLATE, inches
r = RADIUS OF PLATE, inches

$C/10^4 = (fr^2/h)/10^4$

CIRCULAR PLATE CLAMPED AT BOUNDARY	m = NUMBER OF NODAL CIRCLES	n = NUMBER OF NODAL DIAMETERS n = 0	1	2	3
	0	9.936	20.651	33.906	
	1	38.713			
	2	86.516			

CIRCULAR PLATE WITH FREE BOUNDARY	m = NUMBER OF NODAL CIRCLES	n = NUMBER OF NODAL DIAMETERS n = 0	1	2	3
	0			5.110	11.902
	1	8.832	19.970	34.295	51.491
	2	37.487	58.255		

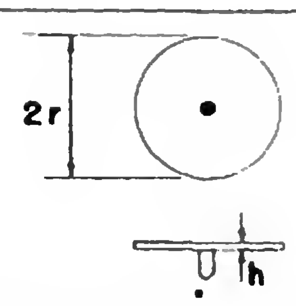
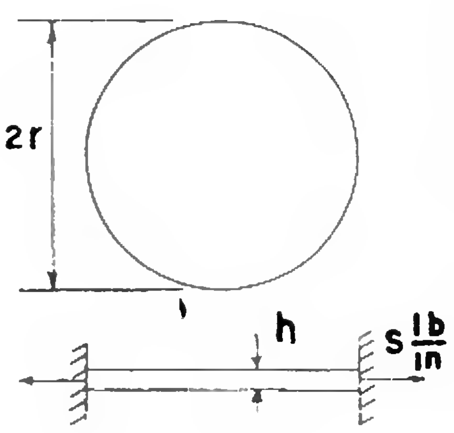
CIRCULAR PLATE CLAMPED AT ITS CENTER	m = NUMBER OF NODAL CIRCLES 0	1	2	3
	3.649	20.349	59.053	116.490

FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(G) Frequency Function = $fr/(s/h)^{1/2}$ for Circular Steel Membranes

f = NATURAL FREQUENCY, cps
r = MEMBRANE RADIUS, inches
s = TENSION, lb/in AT PERIPHERY
h = MEMBRANE THICKNESS, inches

$fr/(s/h)^{1/2}$

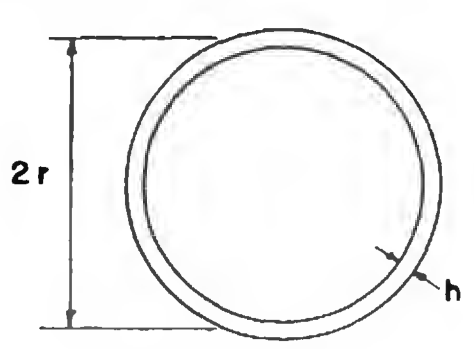


CIRCULAR MEMBRANE	m = NUMBER OF NODAL CIRCLES	n = NUMBER OF NODAL DIAMETERS 0	1	2	3	4	5
	1	14.09	22.49	30.12	37.46	44.56	51.55
	2	32.41	41.22	49.44	57.30	64.94	72.22
	3	50.79	59.71	64.94	76.45	84.55	92.18
	4	69.28	78.09	86.90	95.12	103.34	111.56
	5	87.48	96.88	105.68	113.91	122.13	130.35
	6	106.27	115.08	123.89	132.69	140.91	149.13
	7	124.47	133.87	142.68	150.90	159.70	167.92
	8	143.26	152.07	160.88	169.68	178.49	186.71

Figure 4.60(H) Frequency Constant C = fr^2/h for Steel Ring Vibrating in its Own Plane

f = NATURAL FREQUENCY, cps
r = MEAN RADIUS, inches
h = RING THICKNESS, inches

$C/10^4 = (fr^2/h)/10^4$



CIRCULAR RING	n = NUMBER OF FULL WAVES AROUND PERIPHERY 2	3	4	5	6	7
	54.21	153.33	240.00	475.46	697.48	

FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(I) Frequency Function = fL for Longitudinal Vibration of Steel Beams

f = NATURAL FREQUENCY, cps
L = LENGTH OF BEAM, inches

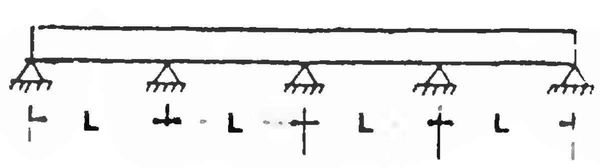
$fL/10^4$

BEAMS	n = NUMBER OF HALFWAVES ALONG LENGTH					
	0	1	2	3	4	5
CLAMPED-FREE	5.05	15.15	25.25	35.35	45.46	55.56
CLAMPED-CLAMPED		10.10	20.20	30.30	40.41	50.51

Figure 4.60(J) Frequency Constant $C = fL^2/r$ for Continuous Steel Beam of k Equal Spans Extreme Ends Simply Supported

f = NATURAL FREQUENCY, cps
L = SPAN LENGTH, inches
r = RADIUS OF GYRATION = $\sqrt{I/A}$ inches

$C/10^4 = (fL^2/r)/10^4$



UNIFORM BEAM EXTREME ENDS SIMPLY SUPPORTED	NUMBER OF SPANS = k	MODE NUMBERS				
		1	2	3	4	5
	1	31.73	126.94	285.61	507.76	793.37
	2	31.73	49.59	126.94	160.66	285.61
	3	31.73	40.52	59.56	126.94	143.98
	4	31.73	37.02	49.59	63.99	126.94
	5	31.73	34.99	44.19	55.29	66.72
	6	31.73	34.32	40.52	49.59	59.56
	7	31.73	33.67	38.40	45.70	53.63
	8	31.73	33.02	37.02	42.70	49.59
	9	31.73	33.02	35.66	40.52	46.46
	10	31.73	33.02	34.99	39.10	44.19
	11	31.73	32.37	34.32	37.70	41.97
	12	31.73	32.37	34.32	37.02	40.52

FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(K) Frequency Constant $C = fL^2/r$ for Continuous Steel Beam of k Equal Spans Extreme Ends Clamped

f = NATURAL FREQUENCY, cps L = SPAN LENGTH, inches r = RADIUS OF GYRATION = $\sqrt{I/A}$ inches

$C/10^4 = (fL^2/r)/10^4$

UNIFORM BEAM EXTREME ENDS CLAMPED	NUMBER OF SPANS = k	MODE NUMBERS 1	2	3	4	5
	1	72.36	198.34	388.75	642.63	959.98
	2	49.59	72.36	160.66	198.34	335.20
	3	40.52	59.56	72.36	143.98	178.25
	4	37.02	49.59	63.99	72.36	137.30
	5	34.99	44.19	55.29	66.72	72.36
	6	34.32	40.52	49.59	59.56	67.65
	7	33.67	38.40	45.70	53.63	62.20
	8	33.02	37.02	42.70	49.59	56.98
	9	33.02	35.66	40.52	46.46	52.81
	10	33.02	34.99	39.10	44.19	49.59
	11	32.37	34.32	37.70	41.97	47.23
	12	32.37	34.32	37.02	40.52	44.94

Figure 4.60(L) Frequency Constant $C = fL^2/r$ for Continuous Steel Beam of k Equal Spans Extreme Ends Clamped — Supported

f = NATURAL FREQUENCY, cps L = SPAN LENGTH, inches r = RADIUS OF GYRATION = $\sqrt{I/A}$ inches

$C/10^4 = (fL^2/r)/10^4$

UNIFORM BEAM EXTREME ENDS CLAMPED - SUPPORTED	NUMBER OF SPANS = K	MODE NUMBERS 1	2	3	4	5
	1	49.59	160.66	335.2	573.21	874.69
	2	37.02	63.99	137.30	185.85	301.05
	3	34.32	49.59	67.65	132.07	160.66
	4	33.02	42.70	56.98	69.51	129.49
	5	33.02	39.10	49.59	61.31	70.45
	6	32.37	37.02	44.94	54.46	63.99
	7	32.37	35.66	41.97	49.59	57.84
	8	32.37	34.99	39.81	45.70	53.63
	9	31.73	34.32	38.40	43.44	49.59
	10	31.73	33.67	37.02	41.24	46.46
	11	31.73	33.67	36.33	39.81	44.19
	12	31.73	33.02	35.66	39.10	42.70

FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(M) Material Correction Factor $K_m = \sqrt{\frac{E}{e}\frac{e_s}{E_s}}$

E = YOUNGS MODULUS FOR MATERIAL, lb/in^2
e = MASS DENSITY FOR MATERIAL, $lb\text{-}sec^2/in^4$
E_s = YOUNGS MODULUS FOR STEEL = 30×10^6
e_s = MASS DENSITY FOR STEEL = 735×10^{-6}

MATERIAL		$K_m = \sqrt{\frac{E}{e}\frac{e_s}{E_s}}$
STEEL		1
ALUMINUM ALLOYS 2S, 3S, 4S, 17S, 24S, 25S, 51S, 52S		0.985
BRASS, BRONZE		0.673
NICKEL		0.940
MONEL METAL		0.872
MAGNESIUM		0.965
TITANIUM	TI-50 A	TI-75 A
TEMPERATURE °F		
80°	0.985	0.975
200°	0.966	0.945
400°	0.932	0.910
600°	0.896	0.873
800°	0.866	0.835
1000°	0.828	0.784

FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(N) Nomograph for Determination of Natural Frequency from L, r and C

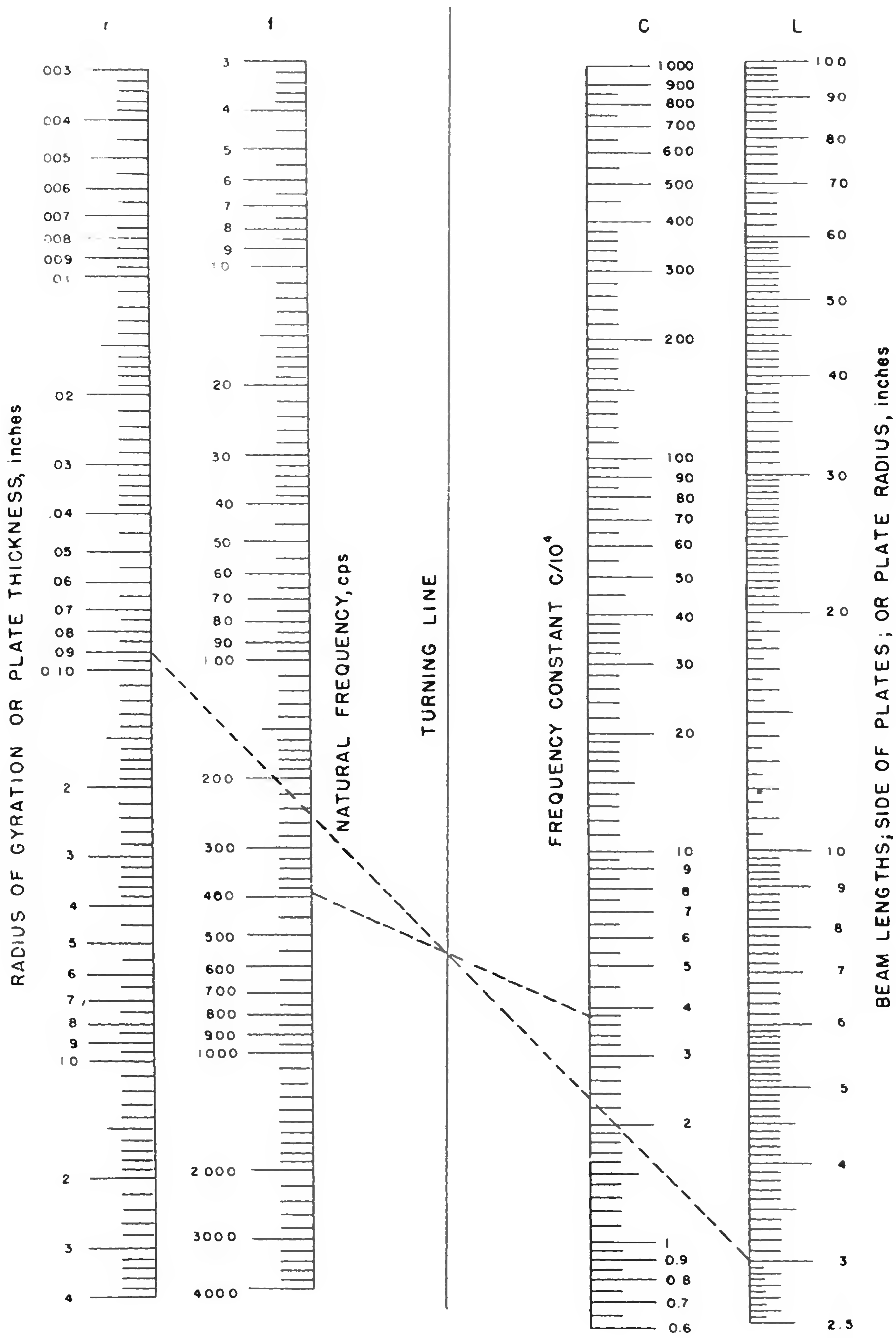


FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(O) Nomograph for Determination of L^2/r from L and r

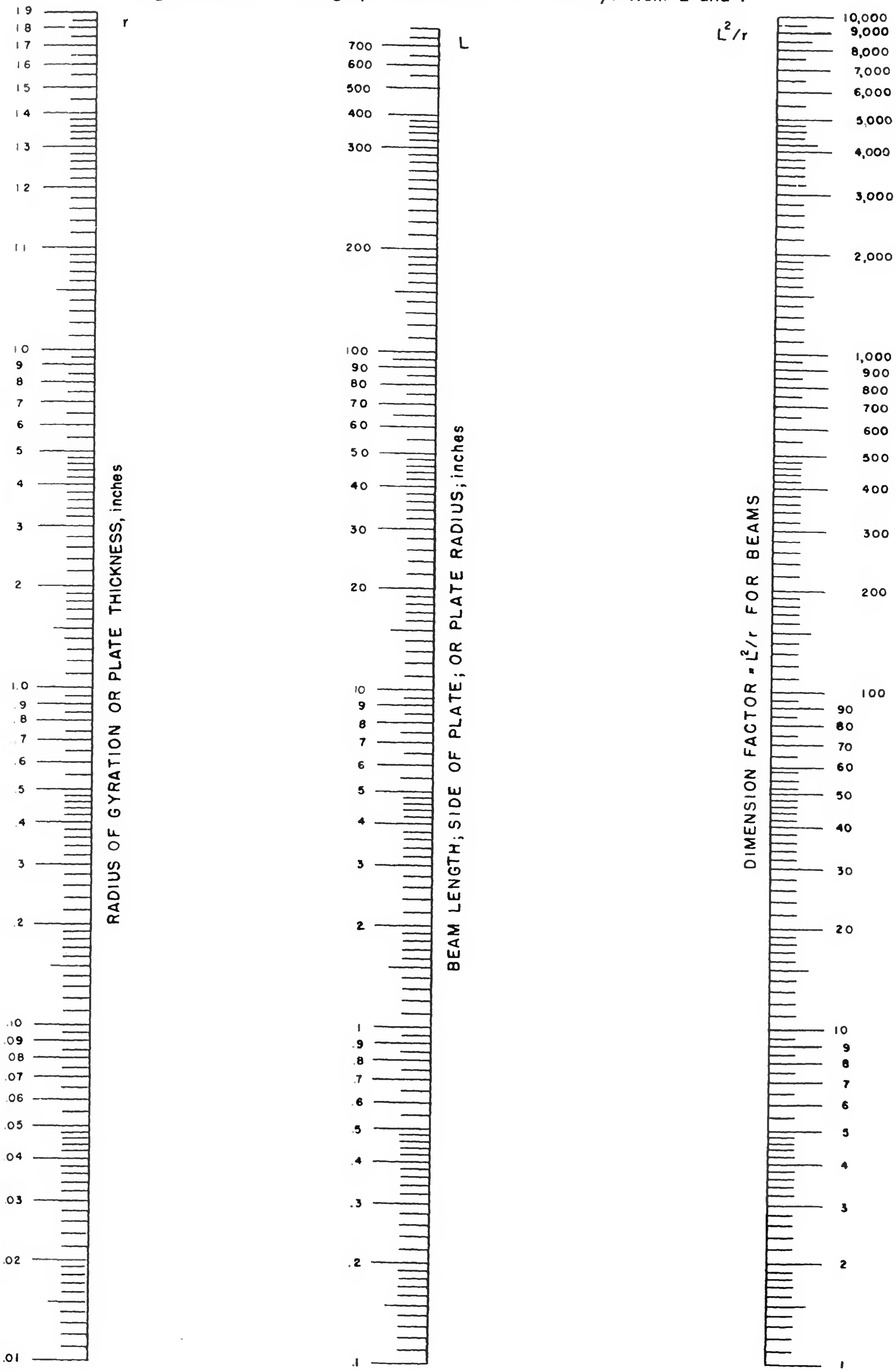


FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(P) Nomograph for Determination of Natural Frequency from L^2/r and C

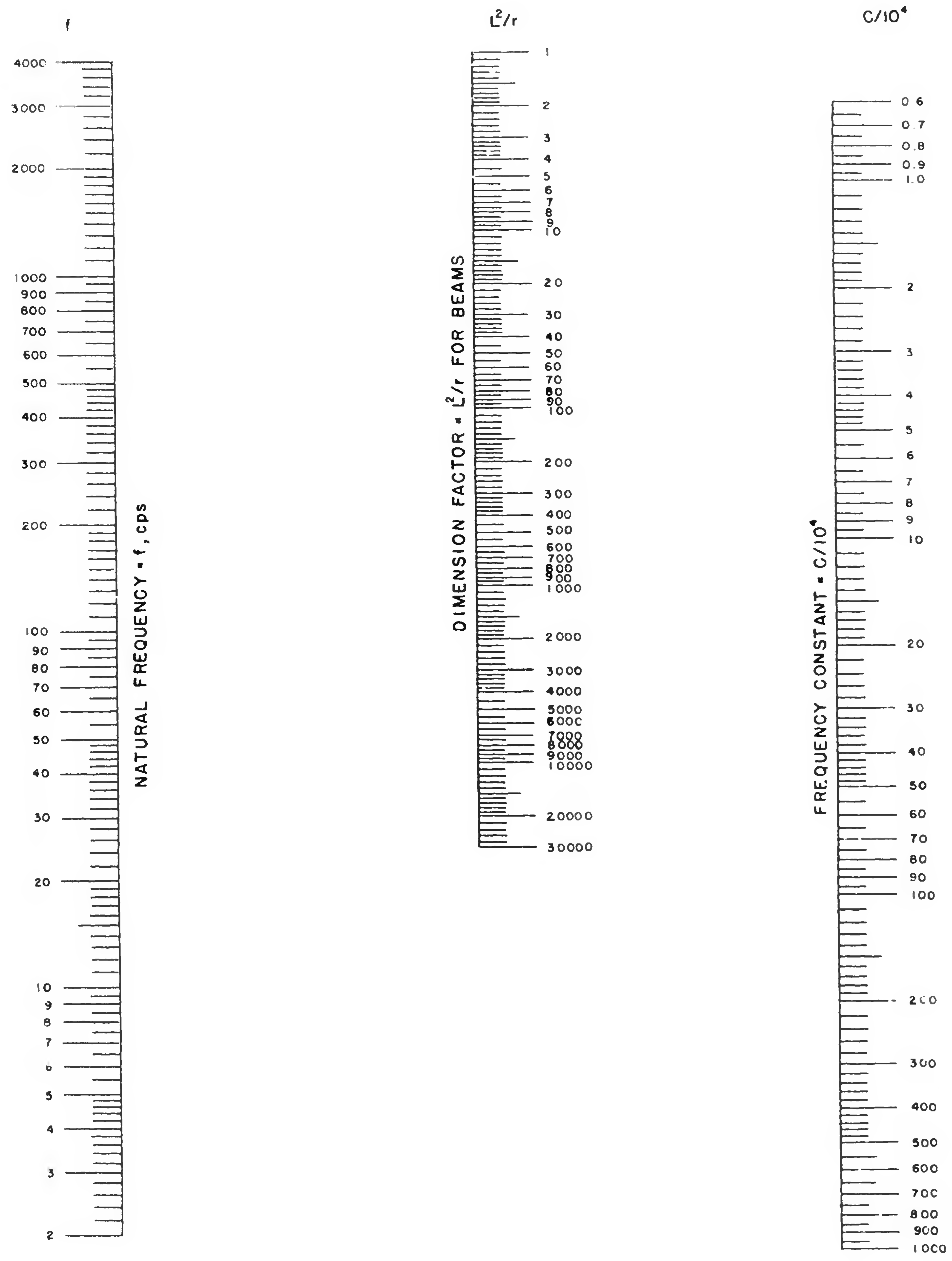


FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(Q) Chart for Determination of Natural Frequency from L^2/r and C

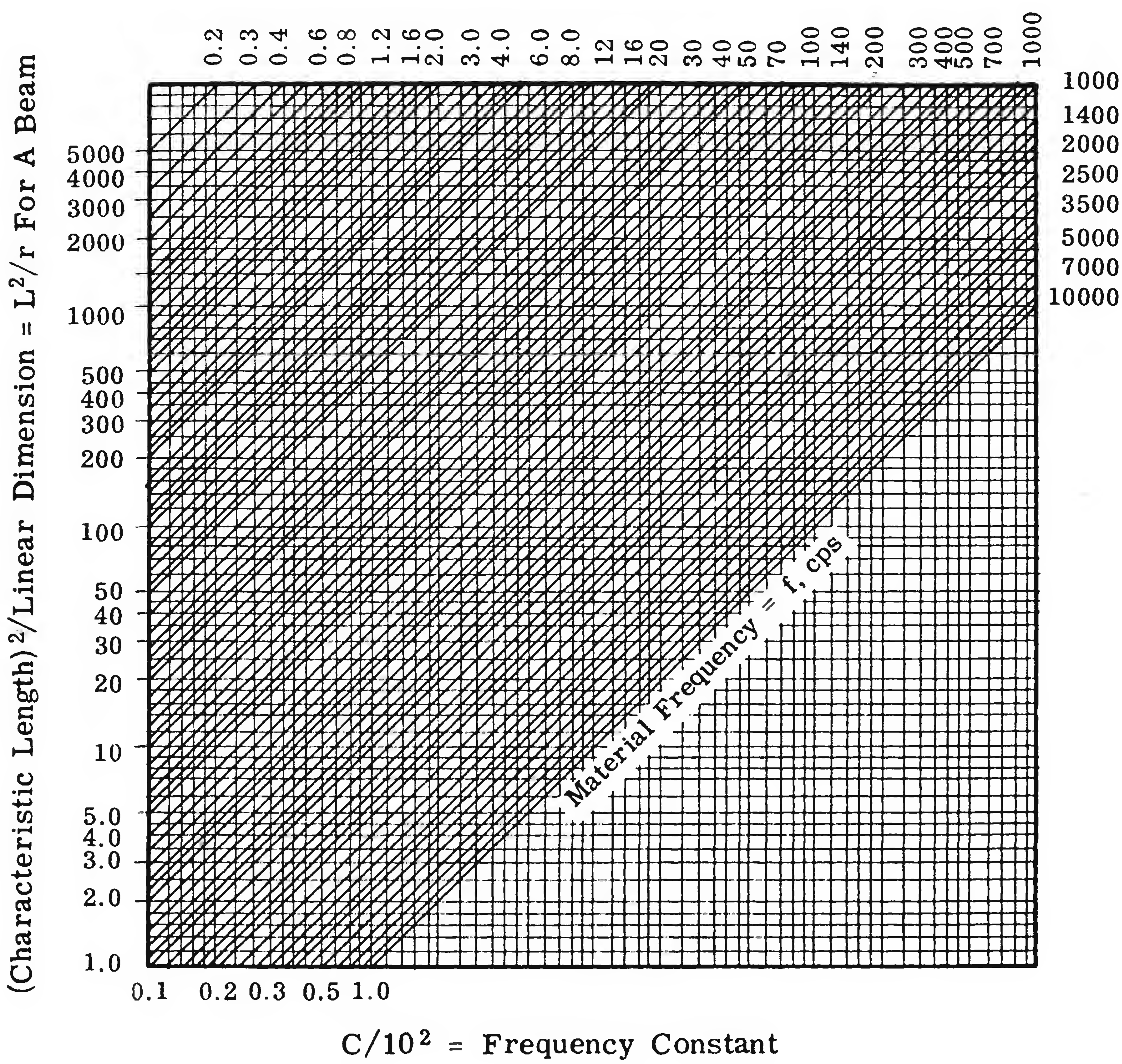
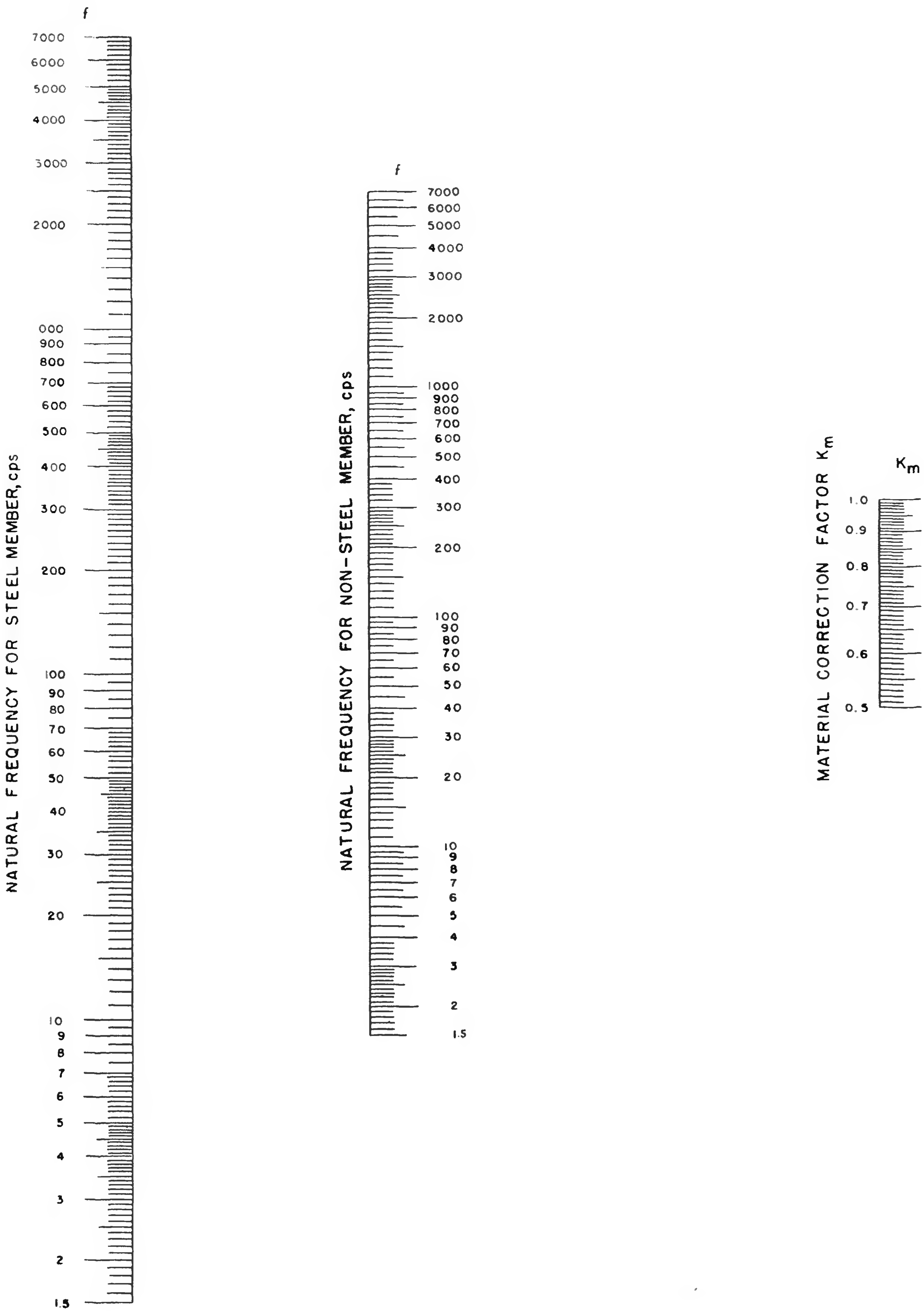


FIGURE 4.60 VIBRATION DESIGN CHARTS (cont.)

Figure 4.60(R) Nomograph for Material Frequency Correction



SECTION 5—AERODYNAMICS

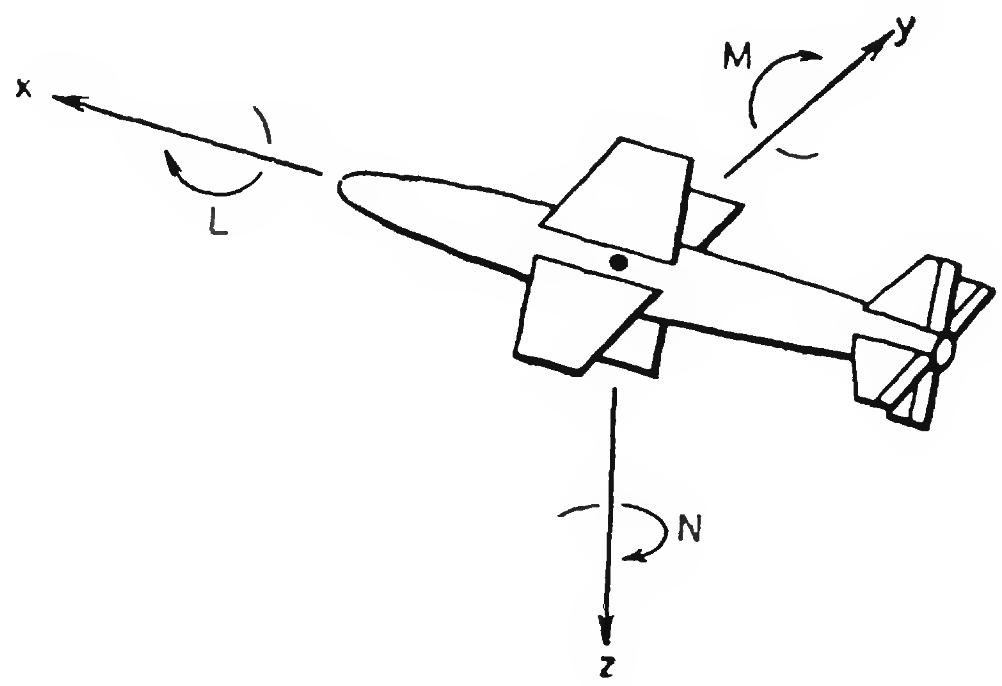
PRINCIPAL NOTATIONS

α	=	angle of attack, degrees or radians as indicated - measured between free stream direction and wing chord or body centerline in pitch plane
c	=	speed of sound, ft/sec
c_p	=	specific heat at constant pressure = 5997 $ft^2/(sec^2)(°R)$
c_v	=	specific heat at constant volume = 4283 $ft^2/(sec^2)(°R)$
C_L	=	lift coefficient = L/qS
C_N	=	normal force coefficient = N/qS
C_{N_α}	=	normal force coefficient curve slope due to angle of attack $\frac{dC_N}{d\alpha}$
C_m	=	pitch moment coefficient = m/qSd
C_n	=	yaw moment coefficient = n/qSd
C_D	=	total drag coefficient = D/qS
C_{D_F}	=	pressure or wave drag coefficient
C_{D_f}	=	friction drag coefficient based on reference area
C_f	=	friction drag coefficient based on wetted area
C_{D_L}	=	drag-due-to-lift coefficient
cp	=	center of pressure
C_l	=	rolling moment coefficient = R/qSd
D	=	drag, lb
δ	=	control-surface differential deflection
d	=	diameter of body of revolution
°F	=	degrees Fahrenheit
F	=	force
k	=	ratio of specific heats = 1.4 for air
g	=	acceleration due to gravity = 32.2 ft/sec^2
h	=	heat transfer coefficient $Btu/sec/ft^2 °F$
h	=	altitude, feet

PRINCIPAL NOTATIONS (cont.)

I	=	total impulse, lb-sec
i	=	control surface incidence (opposite panels deflected in pairs)
L	=	lift, lb
l	=	length of body revolution
λ	=	damping coefficient
M	=	Mach number
μ	=	Mach angle = $\sin^{-1} 1/M$
μ	=	viscosity, slugs/sec ft
m	=	mass, slugs
N	=	normal force, lb
n	=	lateral acceleration in load factors
ω	=	longitudinal weathercock frequency
p	=	pressure, psi or lb/ft^2
Q	=	heat transferred, Btu/sec/ft^2
q	=	$\rho V^2/2 = (k/2)\ pM^2$
ρ	=	density, slug/ft
R	=	universal gas constant = 1714 ft (sec) (°R)
°R	=	deg Rankine
Re	=	Reynolds number
r	=	temperature recovery factor
S	=	reference area
T	=	temperature, °R = 459.6 + °F

FIGURE 5.1 STANDARD NOMENCLATURE FOR AERODYNAMIC ANALYSES



Axis	Linear Velocity	Angular Velocity	Summation of Moment	Summation of Forces	Disp. Angles	Moment of Momentum	Moments of Inertia
X	U	P Rolling Vel.	ΣL	ΣF_x	ϕ	h_x	I_{xx}
Y	V	Q Pitching Vel.	ΣM	ΣF_y	θ	h_y	I_{yy}
Z	W	R Yawing Vel.	ΣN	ΣF_z	ψ	h_z	I_{zz}

Eq. 5.1. Aerodynamic Coefficients

A system of nondimensional coefficients used in aerodynamics. The system permits extrapolation of model data to full-scale designs, development of aids, etc.

Lift coeff. $C_L = L/qS$

Drag coeff. $C_D = D/qS$

Nussealt No. $= \frac{hD}{k}$

Reynolds No. $= \rho VL/\mu$

Stanton No. $= \frac{k}{c_p\mu} = \frac{1}{Pr}$

Prandtl No. $= \frac{c_p\mu}{k}$

Moment Coeff. $C_M = \frac{M}{qS}$

Force Coeff. $C_F = \frac{F}{qS}$

FIGURE 5.1 STANDARD NOMENCLATURE FOR AERODYNAMIC ANALYSES (cont.)

Eq. 5.2. Longitudinal Stability Coefficients -- Linearized

For a given forward speed, the missile equations of motion in the plane of maneuver at constant speed may be written in the following manner:

$$\dot{\gamma} = A\alpha \times Bi$$

$$\ddot{\theta} + C\alpha + D_1 \dot{\theta} + D_2 \dot{\alpha} + D_3 \dot{i} = Ei$$

$$\theta = \alpha + \gamma$$

The aerodynamic stability and control coefficients in the foregoing are defined:

$$A = \frac{pVS}{2m}\left(C_{N_a}\right)$$

$$B = \frac{pVS}{2m}\left(CN_i\right)$$

$$C = \frac{pV^2Sd}{2I}\left(-C_{m_\alpha}\right)$$

$$D_1 = \frac{pVSd^2}{2I}\left(-C_{m_q}\right)$$

$$D_2 = \frac{pVSd^2}{2I}\left(-C_{m_{\dot{\alpha}}}\right)$$

$$D_3 = \frac{pVSd^2}{2I}\left(-C_{m_{\dot{i}}}\right)$$

$$E = \frac{pV^2Sd}{2I}\left(-C_{m_i}\right)$$

where all derivatives are based on reference area S and diameter d and are in radian measure.

Eq. 5.3. Trim Ratio

$$\alpha/i = E/C$$

$$N = \left(\frac{AE}{C} + B\right)\frac{iwV}{1843}$$

TWO- AND THREE-DIMENSIONAL FLOW

The following relations can be used (to approximately second-order accuracy) to obtain the magnitude of pressure change in two- (wedge or straight corner) and three-dimensional (cone) flow conditions whenever the shock is attached to the leading edge of the body and no subsonic conditions exist.

Eq. 5.4. Two-dimensional

$$\frac{\Delta p}{q} = C_1\theta + C_2\theta^2$$

FIGURE 5.1 STANDARD NOMENCLATURE FOR AERODYNAMIC ANALYSES (cont.)

Eq. 5.5. Three-dimensional

$$\frac{\Delta p}{q} = \left(0.083 + \frac{0.096}{M^2}\right)(5.73\theta)^{1.69}$$

where C_1 and C_2 are constants defined and evaluated below:

$$C_1 = \frac{2}{\sqrt{M^2 - 1}}$$

$$C_2 = \frac{\gamma M^4 + (M^2 - 2)^2}{2(M^2 - 1)^2}$$

and θ - deflection angle in radians — positive for compression changes, and negative for expansion.

q = "dynamic pressure" = $0.7pM^2$ = lb/ft^2

M	C_1	C_2
1.5	1.789	2.288
2.0	1.156	1.467
2.5	0.873	1.320
3.0	0.707	1.269
4.0	0.516	1.232
5.0	0.408	1.219

Eq. 5.6. Lift

$$L = \frac{\rho C_L V^2 S}{2} \qquad C_L = \frac{\text{Lift}}{S_w q}$$

The lift of an airframe changes as a result of a change in the angle of attack, since the angle of flow of the air impinging on the wing also changes. In this case

$$C_{L_\alpha} = \frac{dC_L}{d\alpha}$$

where C_{L_α} is the change in the lift coefficient with angle of attack. Similarly, the lift of the airframe changes when the control surface is deflected through the angle δE,

$$C_{L_{\delta E}} = \frac{dC_L}{d\delta E}$$

Eq. 5.7. Drag

The total drag of a missile configuration is:

$$C_D = C_{D_o} + C_{D_L}$$

$$= C_{D_w} + C_{D_f} + C_{D_L}$$

The wave drag of a missile usually constitutes approximately one-half of the total zero-lift drag of a typical supersonic missile, the rest being made up by skin friction.

FIGURE 5.1 STANDARD NOMENCLATURE FOR AERODYNAMIC ANALYSES (cont.)

Drag $= C_D S_w q$

Drag coefficient $C_{D(tot)} = \dfrac{DRAG}{S_w q} = C_{D_p} + C_{D_i}$

Induced drag coefficient $= \dfrac{Di}{S_w q}$

Parasite Drag Coefficient $C_{D_p} = \dfrac{D_p}{S_w q}$

Equivalent Flat Plate Drag Area $f = C_{D_p} \times S_w$

Eq. 5.8. Pressure or Wave Drag Coefficients for aerodynamic surfaces (in the region where two-dimensional flow exists).

(1) Double Wedge

$$C_{D_W} = \frac{4r^2}{\sqrt{M^2 - 1}}$$

(2) Modified Double Wedge (flat - 1/3 chord)

$$C_{D_W} = \frac{6r^2}{\sqrt{M^2 - 1}}$$

(3) Biconvex (double circular arc)

$$C_{D_W} = \frac{5.33r^2}{\sqrt{M^2 - 1}}$$

where r = ratio of maximum thickness to chord of the cross-sectional shape.

The centers of pressure of two-dimensional airfoils at supersonic speeds will be slightly ahead of the midchord point, again depending on the Mach number, thickness ratio, and type of cross-section. For a flat plate of zero thickness and infinite aspect ratio, the center of pressure is at the midchord.

Eq. 5.9. Steady-State Normal Acceleration

(Based on the stability coefficient form) (in number of g's):

$$n = (A\,\alpha + Bi)\,V/1843 \qquad (\alpha \text{ and } i \text{ in deg.})$$

The damping coefficient:

$$\lambda = \frac{A + D}{2}$$

The time to damp to half amplitude:

$$T_{1/2} = 0.693/\lambda \text{ sec}$$

The longitudinal weathercock (fixed wing) frequency:

$$\omega = \sqrt{AD + C - \lambda^2}\ \text{rad/sec.}$$

FIGURE 5.1 STANDARD NOMENCLATURE FOR AERODYNAMIC ANALYSES (cont.)

$A(D)\ \lambda^2$ is always very small compared with C and hence may be omitted in approximating the weathercock frequency. The period of oscillation:

$$P = \frac{2\pi}{\omega} \sec$$

Eq.5.10. Rolling Moments

$$I \ddot{\phi} + K_1\dot{\phi} = K_2\delta + R_i$$

The first term represents the rolling moment created by the roll moment of inertia, I, of the missile under conditions of changing rate of roll velocity, $\ddot{\varphi}$. The second term takes care of the moment created by rotational velocity, $\dot{\phi}$ of the missile, that is, the roll damping moment. The first term on the right side of the equation represents the roll control surface effectiveness, that is, rolling moment per unit differential deflection, δ of the roll control surfaces. The last term in the equation, R_i, covers rolling moments created for any other reason such as misalignments of any kind or induced rolling moments due to coupling or other aerodynamic effects. Dividing this equation by the roll moment of inertia, I, produces

$$\ddot{\phi} + a\dot{\phi} = b\delta + \frac{R_i}{I}$$

where the constants a and b are defined as follows:

$$a = \frac{C_{l_{\dot{\phi}}}\ qSd}{I} = \frac{C_{l_p}\left(\frac{\dot{\phi}b}{2V}\right)qSd}{I}$$

$$C_{l_p} = \frac{dC_l}{d\left(\frac{\dot{\phi}b}{2V}\right)}$$

$$b = \frac{C_{l_\delta}\ qSd}{I}$$

The term $\dot{\phi}b/2V$ represents the lon-dimensional roll velocity. This term is actually the helical angle described by the tip of the wing (of over-all span b) as the missile rolls while moving through air at velocity V. It is this helical angle of the air striking the surface which creates the roll damping moment.

C_{l_δ} is the nondimensional differential roll control surface effectiveness coefficient $dC_l/d\delta$.

Eq. 5.11. Overshoot Factors

The overshoot factors on angle of attack, $\alpha_{max}/\alpha_{trim}$ and n_{max}/n_{trim} (zero-lift trim position with $\alpha = i = 0$) to any wing incidence i are as follows:

$$\alpha_{max} = \frac{(E - BD)}{AD + C} i - e^{\lambda t_m}\left\{\left[\frac{(E-BD)\lambda i}{(AD + C)\omega} - \frac{Bi}{\omega}\right] \sin \omega t_m \right.$$
$$\left. \left[\frac{(E - BD)}{AD + C} i\right] \cos \omega t_m \right\}$$

t_{m_α} = time to reach α_{max}.

$$= \frac{1}{\omega} \tan^{-1}\left[-\frac{B\omega}{E - BD - B\lambda}\right]$$

when E is positive, the time for maximum angle of attack is the same as the time for maximum acceleration,

FIGURE 5.1 STANDARD NOMENCLATURE FOR AERODYNAMIC ANALYSES (cont.)

$$t_{m_\alpha} = t_{m_n}$$

$$n_{max} = \frac{V\mathring{\gamma}\,(\max)}{1843} = (A_{\alpha_{max}} + Bi)\ \frac{V}{1843}$$

where γ, α and i are in deg units

Eq. 5.12. Rankine-Hugoniot Equation

An equation for atmospheric overpressure:

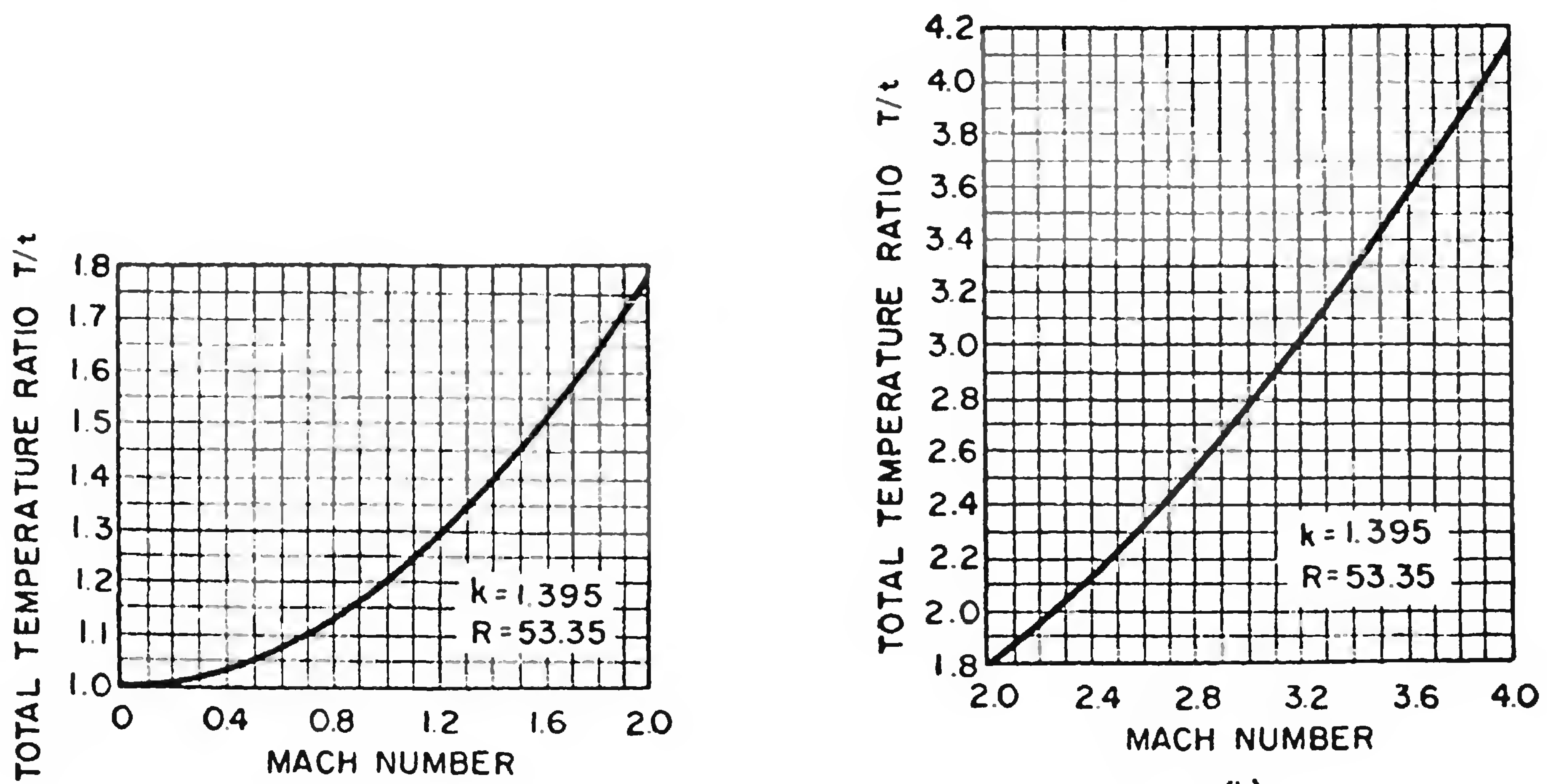
$$P = \frac{2kP_o}{k+1}\left(\frac{V^2}{c^2} - 1\right)$$

where P, the over pressure, is the difference between the wave pressure and that of the undisturbed medium, P_o is the pressure in the undisturbed medium. In other words, V, the velocity of propagation, approaches c as a limiting value when P approaches zero.

Eq. 5.13 Stagnation to Static Pressure Ratio defines the Mach number by the classic Rayleigh pitot tube formula which for air is:

$$\frac{P_o^2}{P_1} = 1.2M^2\left(\frac{7.2M^2}{7M^2 - 1}\right)^{2.5}$$

FIGURE 5.2 TOTAL TEMPERATURE RATIO AS A FUNCTION OF MACH NUMBER FOR NORMAL AIR



(a) (b)

Eq. 5.14 Range The range attained by a missile flying at constant Mach number and altitude, using any type of propulsion, is governed by the mass-ratio (ratio of initial to final weight), the lift-drag ratio, the velocity, and the specific fuel consumption; (i.e., integral of thrust and time):

$$R = \frac{L}{D}\,\frac{V}{c}\,\log_e \frac{W_o}{W_e}$$

R = range, ft $\qquad \frac{L}{D}$ = lift-drag ratio $\qquad$ V = flight speed, ft/sec

FIGURE 5.2 TOTAL TEMPERATURE RATIO AS A FUNCTION OF MACH NUMBER FOR NORMAL AIR (cont.)

c = average specific fuel consumption, lb fuel/sec/lb thrust

W_0 and W_e = initial and final missile gross weight, respectively.

Eq. 5.15. Heat Transfer

The actual rate of heat transfer from the air through the boundary layer into the body itself is a function of many aerodynamic and thermodynamic parameters as well as the shape and character of the structure itself.
These include:

1. Reynolds number (which includes air density and viscosity as well as forward velocity and the size or characteristic length of the structure).
2. Absolute temperature, as well as temperature ratio between the body surface and the free stream.
3. The type of flow, whether laminar or turbulent.
4. The shape of the body.
5. The type, thickness, and shape of the skin and supporting structure.
6. Whether or not the missile is in free flight or a model under tunnel conditions.

The heat transfer is calculated from the relation

$$Q = h(T_w - T)$$

The coefficient h is a function of the Prandtl number, the Reynolds number, thermal conductivity of air, distance along the surface, and particularly whether or not the flow is laminar or turbulent. This coefficient is considerably higher for turbulent than laminar flow, and hence the flow condition over the body has a very important effect on the actual transfer of heat in the body and resulting temperatures therein.

At higher speeds ($M = 3$ to 4 and above), the effects of radiation of heat (within the body) become quite significant and must be included in considerations of heating of missiles. (See Fig. 5.8A)

TEMPERATURE RECOVERY

The stagnation temperature is the temperature of air which has been brought to rest from a given velocity.

Eq. 5.16

$$\frac{T_o}{T} = 1 + \frac{k-1}{2} M^2 = 1 + 0.2M^2$$

The ratio of actual temperature rise in the boundary layer to the adiabatic temperature rise is the temperature recovery factor:

Eq. 5.17

$$r = \frac{T_w - T}{T_o - T}$$

FIGURE 5.2 TOTAL TEMPERATURE RATIO AS A FUNCTION OF MACH NUMBER FOR NORMAL AIR (cont.)

where T_w = temperature of the boundary layer at the missile surface, °R

T = ambient temperature, °R

T_o = adiabatic stagnation temperature, °R

The equation for recovery temperature can be rewritten as follows:

$$\frac{T_w}{T} = 1 + 0.2rM^2$$

For typical recovery factors, see Figs. 5.3 and 5.4

FIGURE 5.3 DATA ON RECOVERY FACTORS FOR LAMINAR BOUNDARY LAYER

Author	Date	Model	Reynolds No.	Mach No.	Temperature Recovery Factor, r
Wimbrow	1949	Cone	2.7×10^6	2.0	0.855 ± 0.008
				1.5	0.855 ± 0.008
		Paraboloid	4.8×10^6	2.0	0.855 ± 0.008
Stalder, Rubesin, Tendeland	1950	Flat plate	$0.2\text{-}1 \times 10^6$	2.4	0.881 ± 0.007
Eber	1952	Cones (10° - 80°) Cone-cylinders	6×10^3	0.88-4.65	0.845 ± 0.008
des Clers and Sternberg	1952	Cone	$0.1\text{-}1.3 \times 10^6$	2.18	0.851 ± 0.007
Slack	1952	Flat plate	$0.15\text{-}3 \times 10^6$	2.4	0.884 ± 0.006
Stine and Scherrer	1952	Cone	$0.2\text{-}1.3 \times 10^6$	2.0	0.845

(Up to a Mach number of 3, the experimental recovery factors agree within one per cent of the theoretical value given by the square root of the Prandtl number evaluated at the adiabatic wall temperature.)

FIGURE 5.4 DATA ON RECOVERY FACTORS FOR TURBULENT BOUNDARY LAYER

Author	Date	Model	Reynolds No.	Mach No.	Temperature Recovery Factor, r
Wimbrow	1949	Cone Paraboloid	2.7×10^6 4.8×10^6	2.0 1.5 2.0	0.885 ± 0.008 0.902 ± 0.005 0.894 ± 0.008
Stalder, Rubesin, Tendeland	1950	Flat Plate	7×10^6	2.4	0.884 0.897 ± 0.007
Hilton	1951	Flat Plate	10×10^6	2.0	0.880 ± 0.004
Eber	1952	Cone and Cone-cylinder	1×10^6 -0.25×10^6	2.87 4.25	0.92 0.97
des Clers	1952	Cone and Cone-cylinder	7×10^6	2-3.4	0.882 ± 0.007
Slack	1952	Flat Plate	3×10^6	2.4	0.906
Stine	1952	10° Cone 40° Cone-cylinder	$0.4\text{-}4 \times 10^6$ $0.3\text{-}1 \times 10^6$	1.97 3.77 3.10 3.77	0.882 ± 0.008 0.885 ± 0.011

(It is evident from the data in this table that, with the exception of Eber's data on cones and cone-cylinders and possibly Slack's data on a flat plate, the recovery factors for a fully turbulent boundary agree within one per cent with the theoretical approximate rule, i.e., equal to the cube root of the Prandtl number.)

FIGURE 5.5 TURBULENT SKIN FRICTION COEFFICIENT

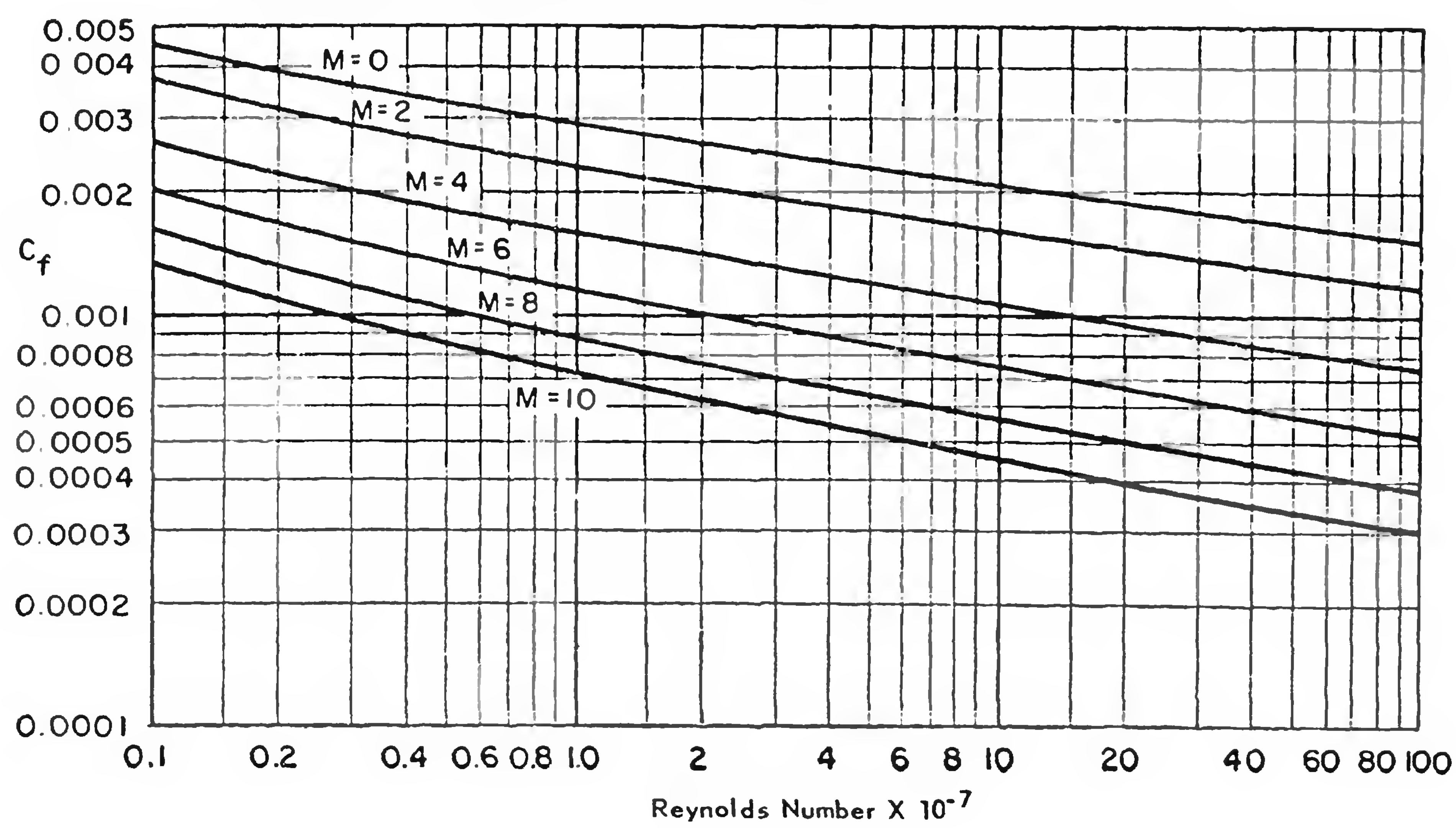
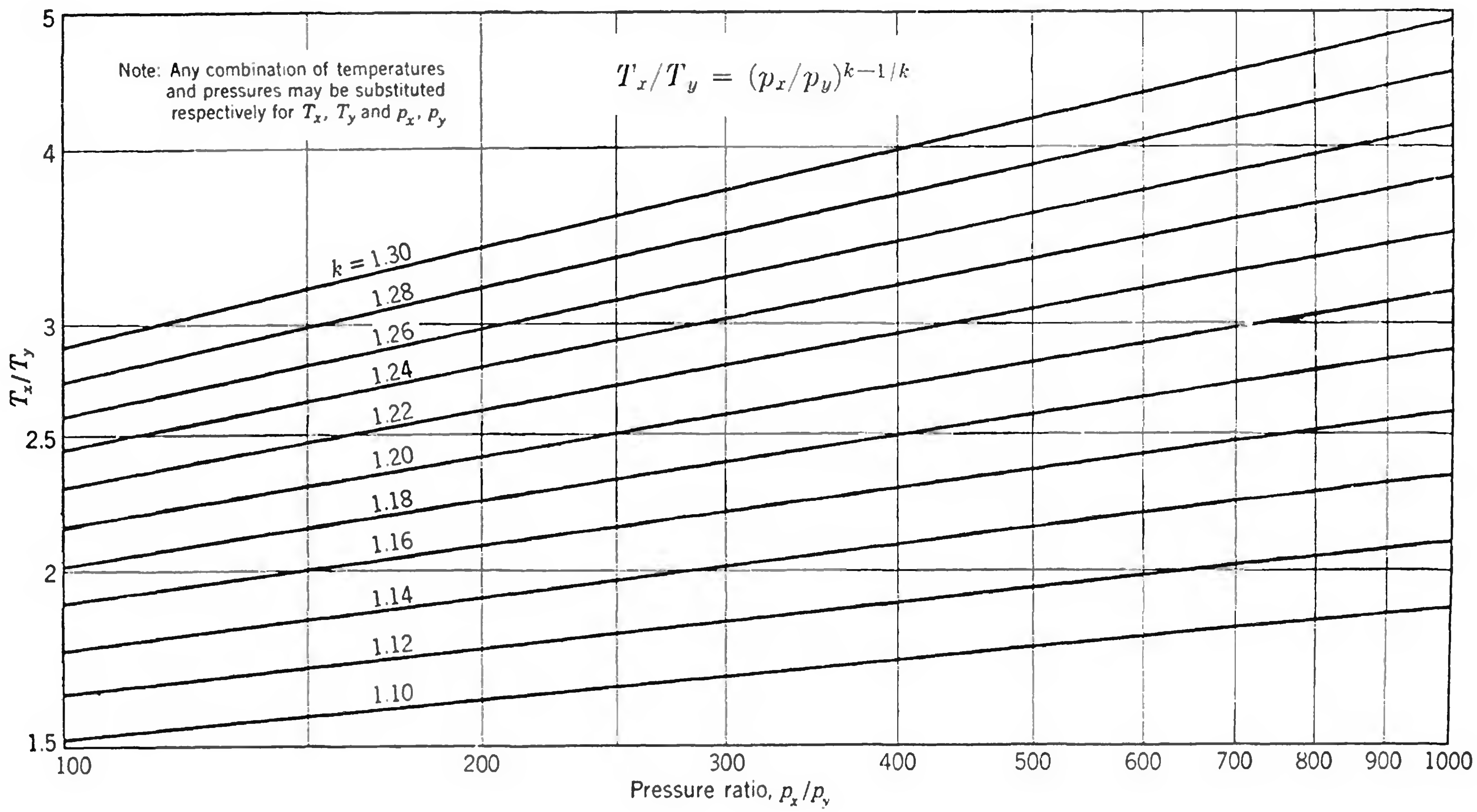
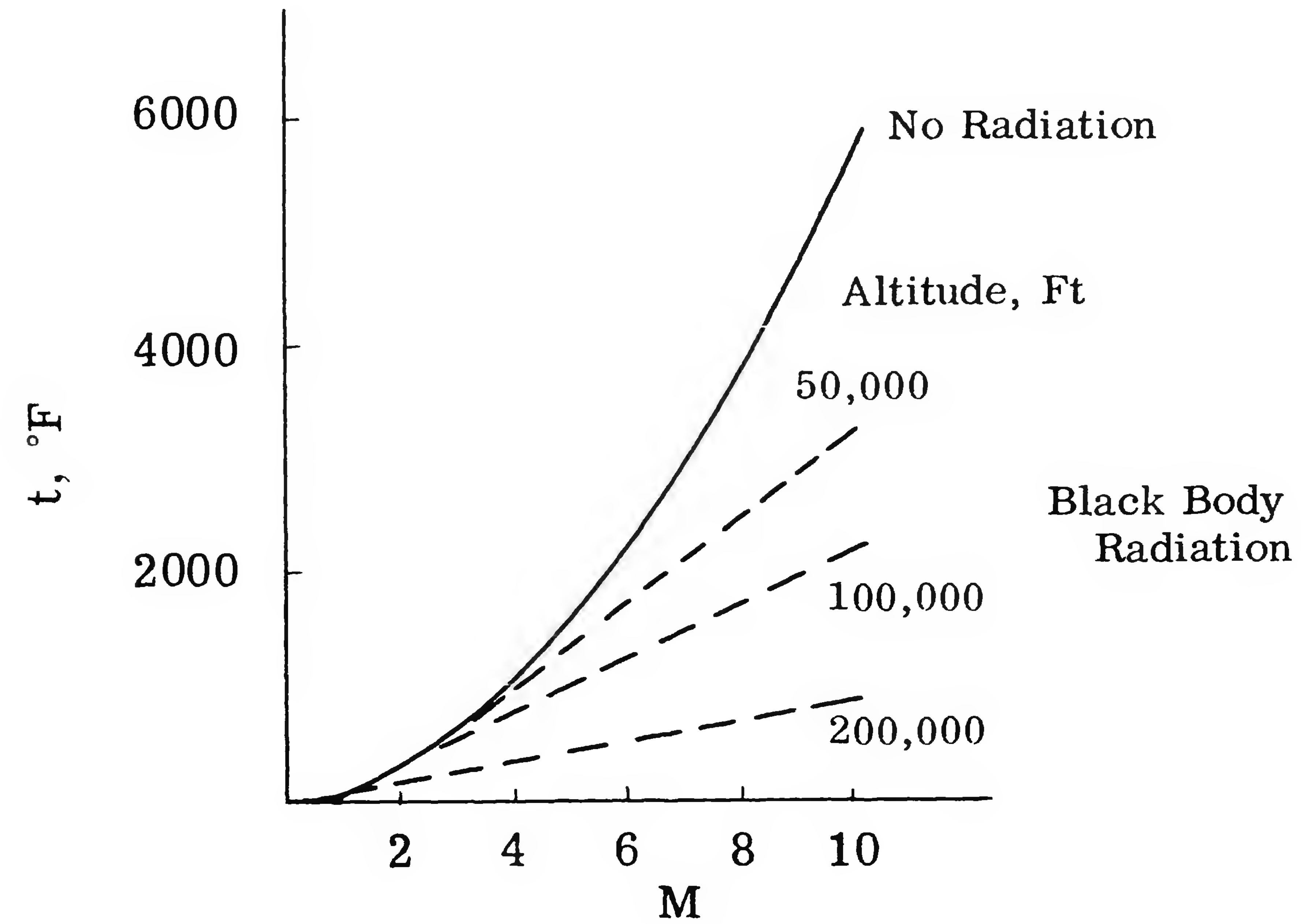


FIGURE 5.6 TEMPERATURE RATIO VS. PRESSURE RATIO FOR ISENTROPIC PROCESS



*Reprinted with permission from G. P. Sutton, ''Rocket Propulsion Elements,'' 1949, John Wiley & Sons.

FIGURE 5.7 EFFECT OF RADIATION ON EQUILIBRIUM TEMPERATURE



[Figure 5.8 (A)]

FIGURE 5.8 (A) STAGNATION TEMPERATURE VS. SPEED

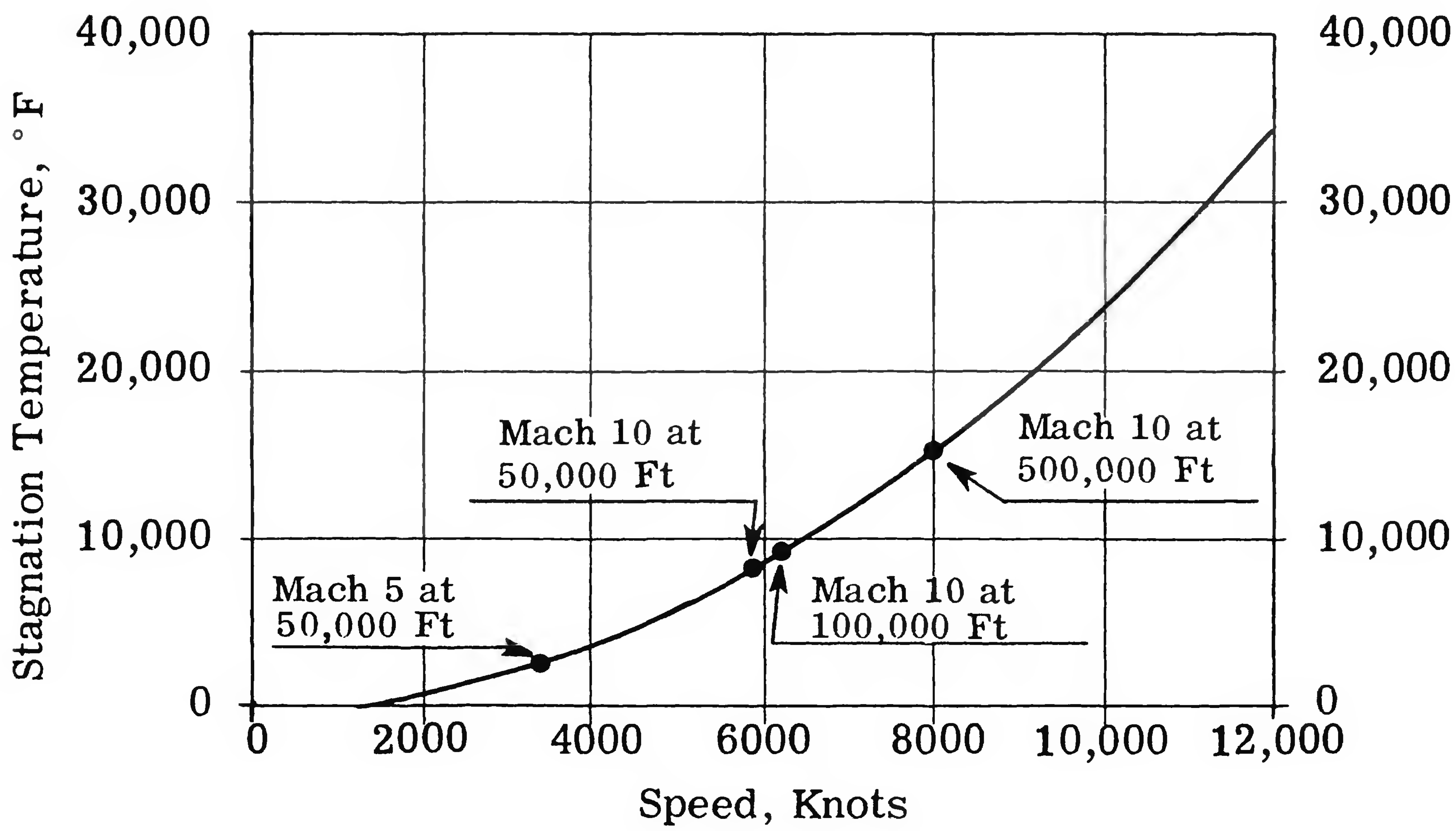
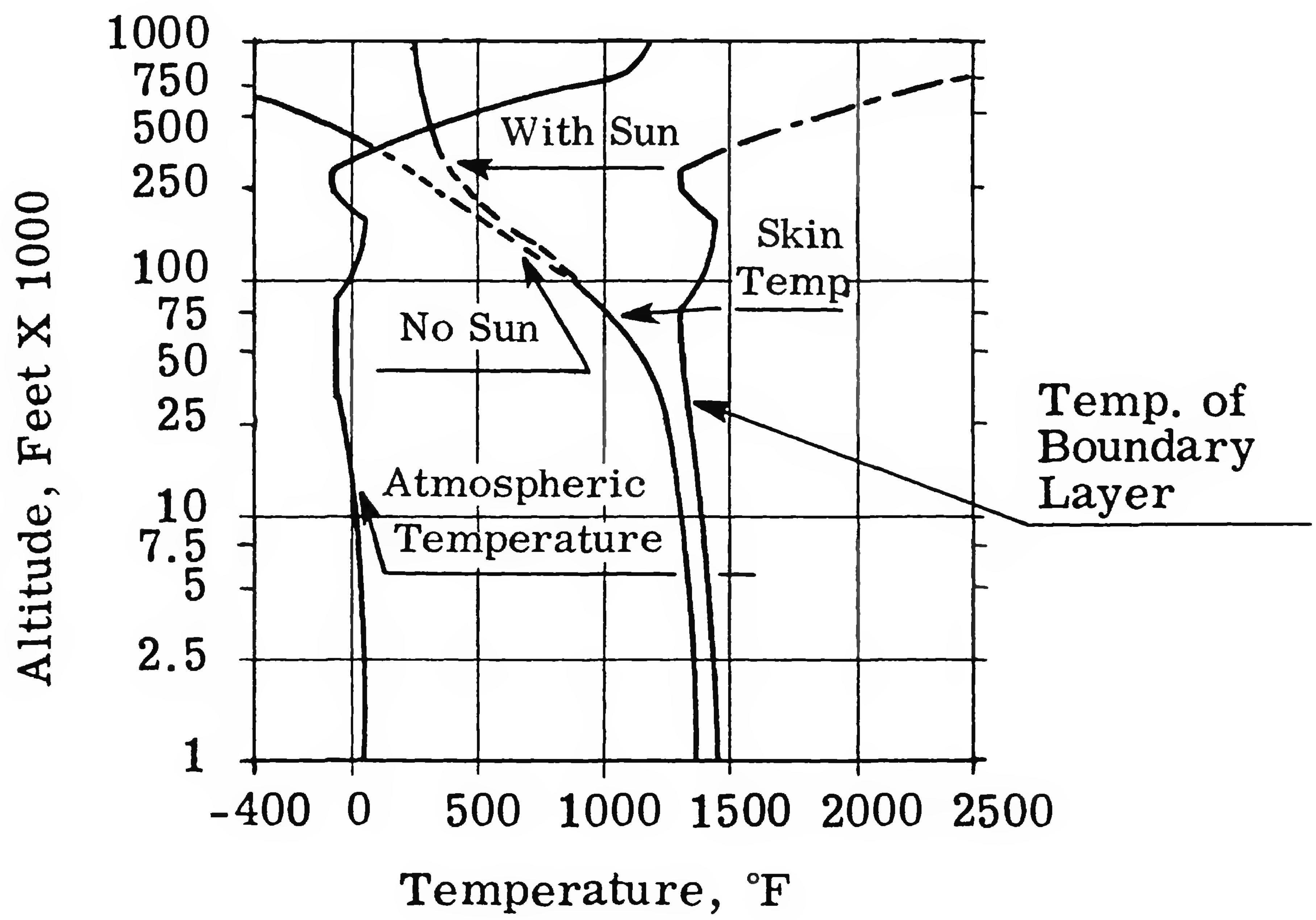


FIGURE 5.8 (B) TEMPERATURE OF A BODY TRAVELING AT 2,610 KNOTS VS. ALTITUDE



Eq. 5.18. Planck Distribution Law

Emission of thermal radiation within an interval $\Delta\lambda$ at wave length λ from unit area of a black body into a hemisphere is:

$$J_\lambda = \frac{c_1}{\lambda^5} \frac{1}{e^{c_2/\lambda T} - 1}$$

where J_λ = the emissive power of unit area in the wave length interval

c_1 = 3.732×10^{-12} watt cm^2

c_2 = 1.436 cm deg

λ = wave length in centimeters

T = absolute temperature (°K)

SECTION 6—AVIONICS

PRINCIPAL NOTATIONS

B = Susceptance, mhos (in AC circuits) (Quadrature part of admittance)
C = Capacitance, farads
E = Voltage, volts
E_g = Vacuum tube grid voltage, volts
E_p = Vacuum tube plate voltage, volts
E_s = Signal voltage, volts
f = Frequency, cps
f_r = Resonant frequency, cps
G = Conductance, mhos (in DC circutts)
G = Power gain
g_m = Mutual conductance, mhos
I = Current, amp
i = Instantaneous current at time t, amp
I_p = Vacuum tube plate current, amp
K = Coupling coefficient
kc = Frequency, kc
L = Inductance, henries
$\frac{L}{R}$ = Time constant of RL circuit, sec
M = Mutual inductance, henries
mc = Frequency, mc
P = Power, watts
Q = Figure of merit
R = Radar, range
R = Resistance, ohms
RC = Time constant of RC circuit, sec
R_L = Vacuum tube plate load resistance, ohms
rp = Vacuum tube dynamic plate resistance, ohms

PRINCIPAL NOTATIONS (cont.)

V_C = Reactive volts across capacitance, C

V_L = Reactive volts across inductance, L

V_R = Volts across resistance, R

X_C = Capacitance reactance, ohms

X_L = Inductive reactance, ohms

Y = Admittance, mhos (in AC circuits)

Z = Impedance, ohms

δ = Time constant - time for i or V to fall to $\frac{1}{\epsilon}$ or 36.8 % of its initial value or to rise to $(1 - \frac{1}{\epsilon})$ or 63.2 % of its final value

θ = Phase angle, degrees

λ = Wave length

μ = Amplification factor

τ = Pulse duration, microsec

Eq. 6.1 Ohm's Law

Direct Current

$E = IR$

$P = EI = I^2R$

Alternating Current

$E = IZ$

$P = EI \cos\theta \qquad PF = \cos\theta$

Phase Angle

		θ	PF
Capacitive circuit: I leads E	Resistive circuit	0°	1
Inductive circuit: I lags E	Reactive circuit	90°	0
Series circuit: arc tan $\frac{X}{R}$	Resonant circuit	0°	1

Eq. 6.2 Coupled Inductance

Series

$L = L_1 + L_2 + 2M$ (aiding)

$L = L_1 + L_2 - 2M$ (opposing)

Parallel

$$L = \frac{1}{\frac{1}{L_1 + M} + \frac{1}{L_2 + M}} \quad \text{(aiding)}$$

$$L = \frac{1}{\frac{1}{L_1 - M} + \frac{1}{L_2 - M}} \quad \text{(opposing)}$$

Eq. 6.3 Mutual Inductance

$$M = \frac{L_a - L_o}{4}$$

L_a = total aiding
L_o = total opposing

Eq. 6.4 Coupling Coefficient

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

Eq. 6.5 Circuit Resonance

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

Eq. 6.6 Reactance

$X_L = 2\pi fL$ (inductive)

$X_C = \frac{1}{2\pi fC}$ (capacitive)

Eq. 6.7 Figure of Merit

$$Q = \frac{X_L}{R_L} \qquad R_L = \text{resistance acting in series with inductance}$$

$$Q = \frac{X_C}{R_C} \qquad R_C = \text{resistance acting in series with capacitance}$$

Eq. 6.8 Impedance

Series

$$Z_t = \sqrt{R_t^2 + X_t^2} \qquad R = Z \cos \theta \qquad R_t = R_1 + R_2 + - + R_n$$

$$X = Z \sin \theta \qquad X_t = X_1 + X_2 + - - + X_n$$

Parallel

$$Z_t = \frac{1}{\sqrt{G_t^2 + B_t^2}}$$

Eq. 6.9 Conductance

$$G = \frac{1}{R} = \frac{I}{E}$$

$$G_t = G_1 + G_2 + - + G_n$$

Eq. 6.10 Susceptance

$$B = \frac{X}{Z_t^2} = \frac{X}{R^2 + X^2} \simeq \frac{1}{X}$$

Eq. 6.11 Admittance

$$Y = \sqrt{G^2 + B^2} = \frac{1}{\sqrt{R^2 + X^2}} \simeq \frac{1}{Z}$$

Eq. 6.12 Current — Steady State

Capacitive Circuit

$$I = \frac{E}{X_c} = 2\pi fCE$$

Inductive Circuit

$$I = \frac{E}{X_L} = \frac{E}{2\pi fL}$$

Eq. 6.13 Current and Voltage -- Transient

RC Network | RL Network

RC Charging	RC Discharging	RL Charging	RL Discharging
$i = \frac{E}{R} \epsilon^{-\frac{t}{RC}}$	$i = \frac{E}{R} \epsilon^{-\frac{t}{RC}}$	$i = \frac{E}{R}\left(1 - \epsilon^{-\frac{t}{L/R}}\right)$	$i = \frac{E}{R} \epsilon^{-\frac{t}{L/R}}$
$V_c = E\left(1 - \epsilon^{-\frac{t}{RC}}\right)$	$V_c = E\epsilon^{-\frac{t}{RC}}$	$V_L = E\epsilon^{-\frac{t}{L/R}}$	$V_L = E\epsilon^{-\frac{t}{L/R}}$
$V_R = E\epsilon^{-\frac{t}{RC}}$	$V_R = V_C$	$V_R = E\left(1 - \epsilon^{-\frac{t}{L/R}}\right)$	$V_R^- = V_L$

Eq. 6.14 Vacuum Tube Characteristics

Amplification factor

$$\mu = \frac{\Delta E_p}{\Delta E_g}$$

Mutual conductance

$$g_m = \frac{\Delta I_p}{\Delta E_g}$$

Gain per stage

$$\text{Gain} = \mu \frac{R_L}{R_L + r_p} \qquad r_p = \frac{\Delta E_p}{\Delta I_p}$$

Power output

$$\text{Power} = R_L \left(\frac{\mu E_s}{r_p + R_L}\right)^2$$

Eq. 6.15 Frequency-wavelength

$f\lambda$ = C; mc/sec x wave length in meters

= speed of light in meters/microsec

= 299.8 m/μs

use/meter = 300 m/μs and the inverse proportionality of λ and f to obtain any desired conversion

FIGURE 6.I (A) REACTANCE NOMOGRAM - I CYCLE TO I000 CYCLES

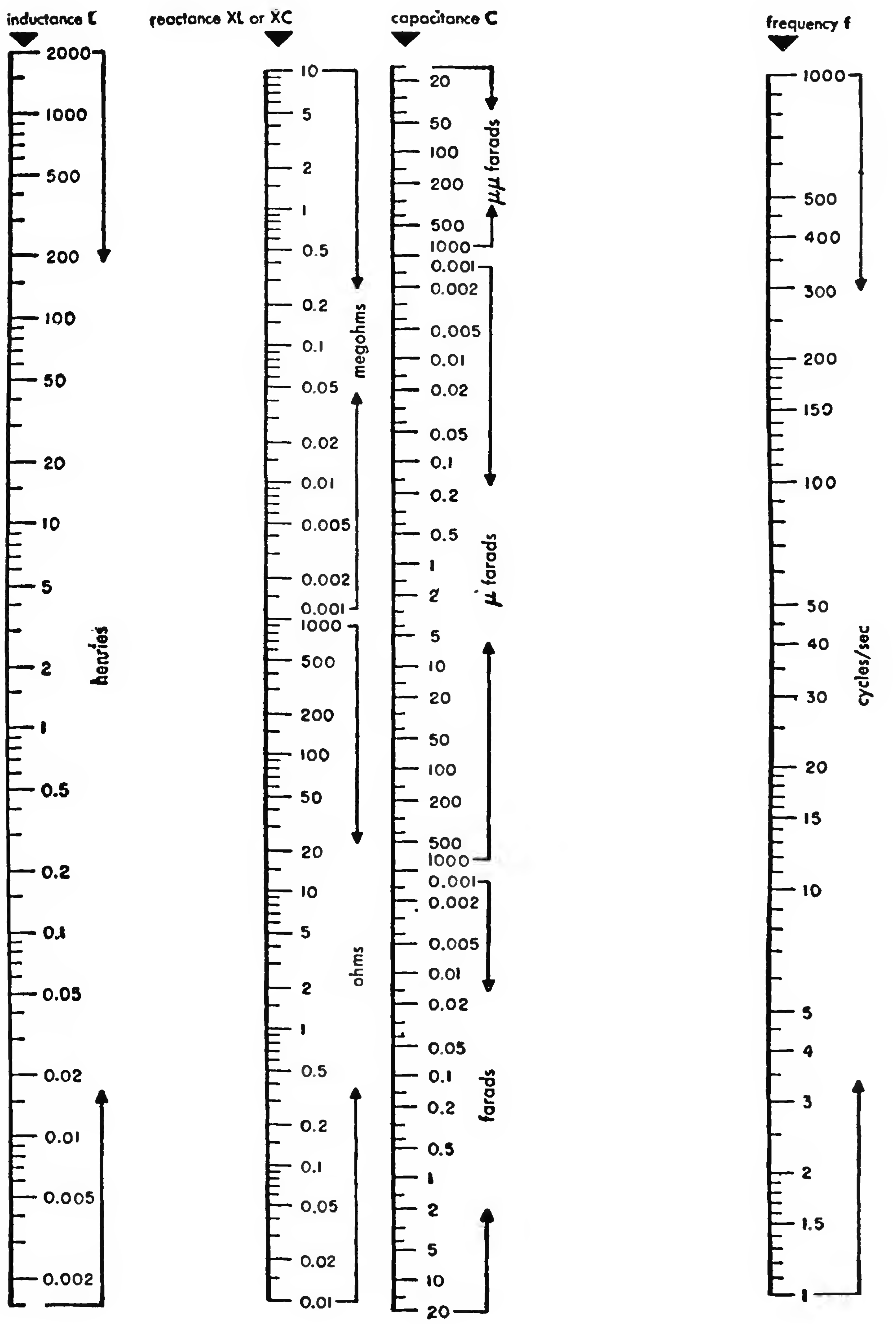


FIGURE 6.1 (B) REACTANCE NOMOGRAM - 1 KILOCYCLE TO 1000 KILOCYCLES

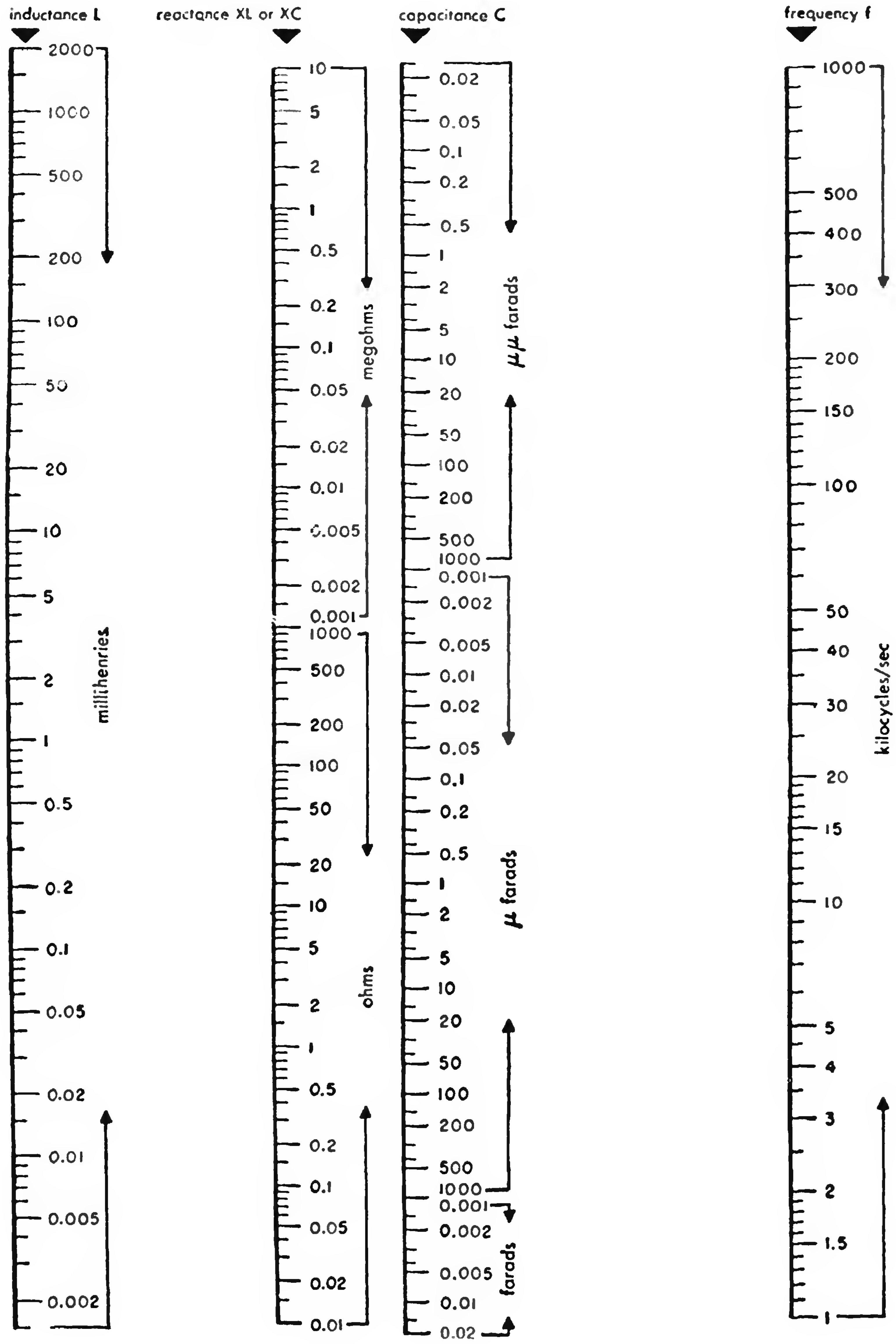


FIGURE 6.1 (C) REACTANCE NOMOGRAM - 1 MEGACYCLE TO 1000 MEGACYCLES

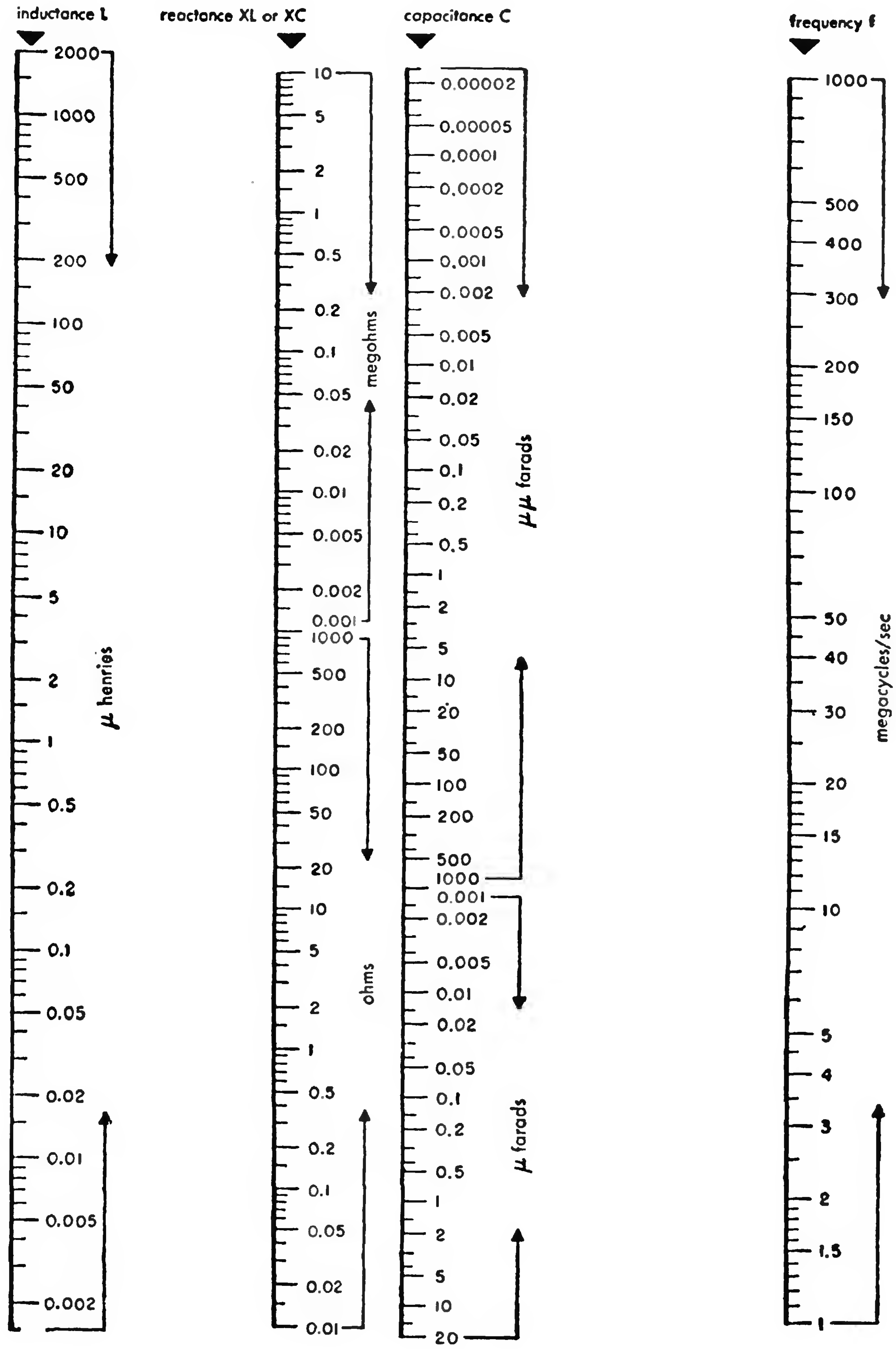


FIGURE 6.2 DB RATIOS

db Expressed as Power and Voltage (or Current) Ratios

Power Ratio	Voltage Ratio	← − db + →	Voltage Ratio	Power Ratio
1.000	1.0000	0	1.000	1.000
.9772	.9886	.1	1.012	1.023
.9550	.9772	.2	1.023	1.047
.9333	.9661	.3	1.035	1.072
.9120	.9550	.4	1.047	1.096
.8913	.9441	.5	1.059	1.122
.8710	.9333	.6	1.072	1.148
8511	9226	.7	1.084	1.175
.8318	.9120	.8	1.096	1.202
.8128	.9016	.9	1.109	1.230
.7943	.8913	1.0	1.122	1.259
.6310	.7943	2.0	1.259	1.585
.5012	.7079	3.0	1.413	1.995
.3981	.6310	4.0	1.585	2.512
.3162	.5623	5.0	1.778	3.162
.2512	.5012	6.0	1.995	3.981
.1995	.4467	7.0	2.239	5.012
.1585	.3981	8.0	2.512	6.310
.1259	.3548	9.0	2.818	7.943

Power Ratio	Voltage Ratio	← − db + →	Voltage Ratio	Power Ratio
.10000	.3162	10.0	3.162	10.00
.07943	.2818	11.0	3.548	12.59
.06310	.2512	12.0	3.981	15.85
.05012	.2293	13.0	4.467	19.95
.03981	1995	14.0	5.012	25.12
.03162	.1778	15.0	5.623	31.62
.02512	.1585	16.0	6.310	39.81
.01995	.1413	17.0	7.079	50.12
.01585	.1259	18.0	7.943	63.10
.01259	.1122	19.0	8.913	79.43
.01000	.1000	20.0	10.000	100.00
10^{-3}	3.162×10^{-2}	30.0	3.162×10	10^{3}
10^{-4}	10^{-2}	40.0	10^{2}	10^{4}
10^{-5}	3.162×10^{-3}	50.0	3.162×10^{2}	10^{5}
10^{-6}	10^{-3}	60.0	10^{3}	10^{6}
10^{-7}	3.162×10^{-4}	70.0	3.162×10^{3}	10^{7}
10^{-8}	10^{-4}	80.0	10^{4}	10^{8}
10^{-9}	3.162×10^{-5}	90.0	3.162×10^{4}	10^{9}
10^{-10}	10^{-5}	100.0	10^{5}	10^{10}

Power Ratios Expressed in +db

Power Ratio	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	.000	.414	.792	1.139	1.461	1.761	2.041	2.304	2.553	2.788
2	3.010	3.222	3.424	3.617	3.802	3.979	4.150	4.314	4.472	4.624
3	4.771	4.914	5.051	5.185	5.315	5.441	5.563	5.682	5.798	5.911
4	6.021	6.128	6.232	6.335	6.435	6.532	6.628	6.721	6.812	6.902
5	6.990	7.076	7.160	7.243	7.324	7.404	7.482	7.559	7.634	7.709
6	7.782	7.853	7.924	7.993	8.062	8.129	8.195	8.261	8.325	8.388
7	8.451	8.513	8.573	8.633	8.692	8.751	8.808	8.865	8.921	8.976
8	9.031	9.085	9.138	9.191	9.243	9.294	9.345	9.395	9.445	9.494
9	9.542	9.590	9.638	9.685	9.731	9.777	9.823	9.868	9.912	9.956

For Power Ratios between 0.01 and 0.099, use above table to get db for 100 times the ratio and subtract 20 db.
For Power Ratios between 0.1 and 0.99, use above table to get db for 10 times the ratio and subtract 10 db.
For Power Ratios between 1 and 9.9, use above table directly.
For Power Ratios between 10 and 99, use above table to get db for 1/10th of the ratio and add 10 db.
For Power Ratios between 100 and 990, use above table to get db for 1/100th of the ratio and add 20 db.

Voltage (or Current) Ratios Expressed in +db

Voltage Ratio	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	.000	.828	1.584	2.279	2.923	3.522	4.082	4.609	5.105	5.575
2	6.021	6.444	6.848	7.235	7.604	7.959	8.299	8.627	8.943	9.248
3	9.542	9.827	10.103	10.370	10.630	10.881	11.126	11.364	11.596	11.821
4	12.041	12.256	12.465	12.669	12.869	13.064	13.255	13.442	13.625	13.804
5	13.979	14.151	14.320	14.486	14.648	14.807	14.964	15.117	15.269	15.417
6	15.563	15.707	15.848	15.987	16.124	16.258	16.391	16.521	16.650	16.777
7	16.902	17.025	17.147	17.266	17.385	17.501	17.616	17.730	17.842	17.953
8	18.062	18.170	18.276	18.382	18.486	18.588	18.690	18.790	18.890	18.988
9	19.085	19.181	19.276	19.370	19.463	19.554	19.645	19.735	19.825	19.913

For Voltage Ratios between 0.01 and 0.099, use above table to get db for 100 times the ratio and subtract 40 db.
For Voltage Ratios between 0.1 and 0.99, use above table to get db for 10 times the ratio and subtract 20 db.
For Voltage Ratios between 1 and 9.9, use above table directly.
For Voltage Ratios between 10 and 99, use above table to get db for 1/10th of the ratio and add 20 db.
For Voltage Ratios between 100 and 990, use above table to get db for 1/100th of the ratio and add 40 db.

FIGURE 6.3 CONVERSION TABLE, GAIN TO DECIBELS

M	m, db	M	m, db
0	$-\infty$	4	+12*
1/100	-40	8	+18*
1/10	-20	10	+20
1/4	-12*	16	+24*
1/2	- 6*	20	+26*
0.707	- 3*	32	+30*
1	- 0	100	+40
1.414	+ 3*	1000	+60
2	+ 6*		

* These values are approximate but are accurate enough for servo design.

M = Magnitude of transfer function; $\frac{\text{output}}{\text{input}}$. m = Corresponding magnitude in db.

FIGURE 6.4 (A) DB EXPRESSED IN WATTS AND VOLTS

DB*	Above Zero Level		Below Zero Level	
	Watts	Volts	Watts	Volts
0	0.00600	1.73	6.00×10^{-3}	1.73
1	0.00755	1.94	4.77×10^{-3}	1.54
2	0.00951	2.18	3.78×10^{-3}	1.38
3	0.0120	2.45	3.01×10^{-3}	1.23
4	0.0151	2.74	2.39×10^{-3}	1.09
5	0.0190	3.08	1.90×10^{-3}	0.974
6	0.0239	3.46	1.51×10^{-3}	0.868
7	0.0301	3.88	1.20×10^{-3}	0.774
8	0.0378	4.35	9.51×10^{-4}	0.690
9	0.0477	4.88	7.55×10^{-4}	0.614
10	0.0600	5.48	6.00×10^{-4}	0.548
11	0.0755	6.14	4.77×10^{-4}	0.488
12	0.0951	6.90	3.78×10^{-4}	0.435
13	0.120	7.74	3.01×10^{-4}	0.388
14	0.151	8.68	2.39×10^{-4}	0.346
15	0.190	9.74	1.90×10^{-4}	0.308
16	0.239	10.93	1.51×10^{-4}	0.275
17	0.301	12.26	1.20×10^{-4}	0.245
18	0.378	13.76	9.51×10^{-5}	0.218
19	0.477	15.44	7.55×10^{-5}	0.194
20	0.600	17.32	6.00×10^{-5}	0.173
25	1.90	30.8	1.90×10^{-5}	0.0974
30	6.00	54.8	6.00×10^{-6}	0.0548
35	19.00	97.4	1.90×10^{-6}	0.0308
40	60.00	173.0	6.00×10^{-7}	0.0173
45	190.00	308.0	1.90×10^{-7}	0.00974
50	600.00	548.0	6.00×10^{-8}	0.00548
60	6,000.00	1,730.0	6.00×10^{-9}	0.00173
70	60,000.00	5,480.0	6.00×10^{-10}	0.000548
80	600,000.00	17,300.0	6.00×10^{-11}	0.000173

* Zero db = 6 milliwatts into a 500 ohm load. Power ratios hold for any impedance, but voltages must be referred to an impedance load of 500 ohms.

FIGURE 6.4(B) SOUND PRESSURE DB ABOVE REFERENCE PRESSURE LEVEL OF 0.0002 MICROBARS (29.00×10^{-10} PSI)

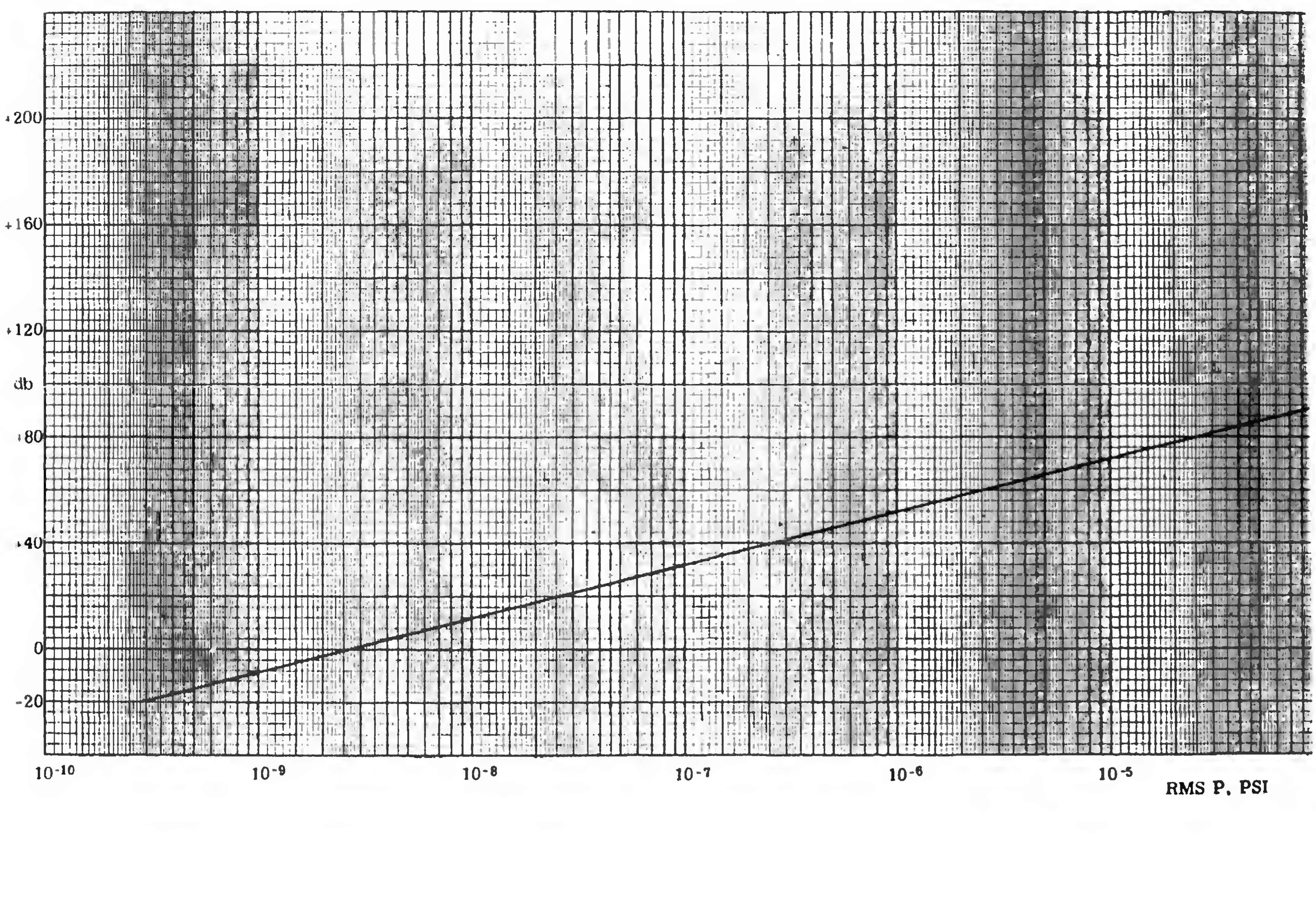
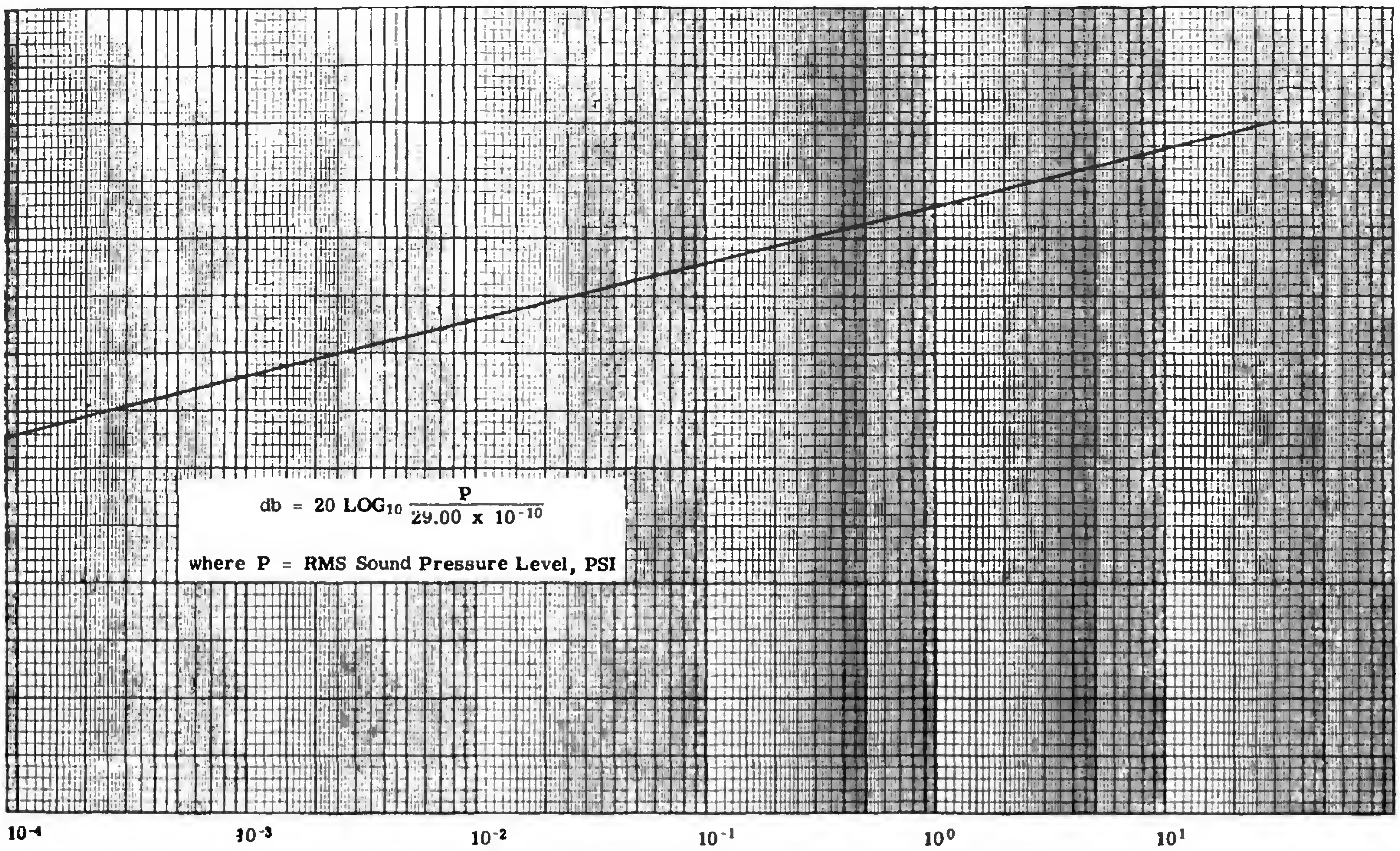


FIGURE 6.4(B) SOUND PRESSURE DB ABOVE REFERENCE PRESSURE LEVEL OF 0.0002 MICROBARS (29.00×10^{-10} PSI) (cont.)



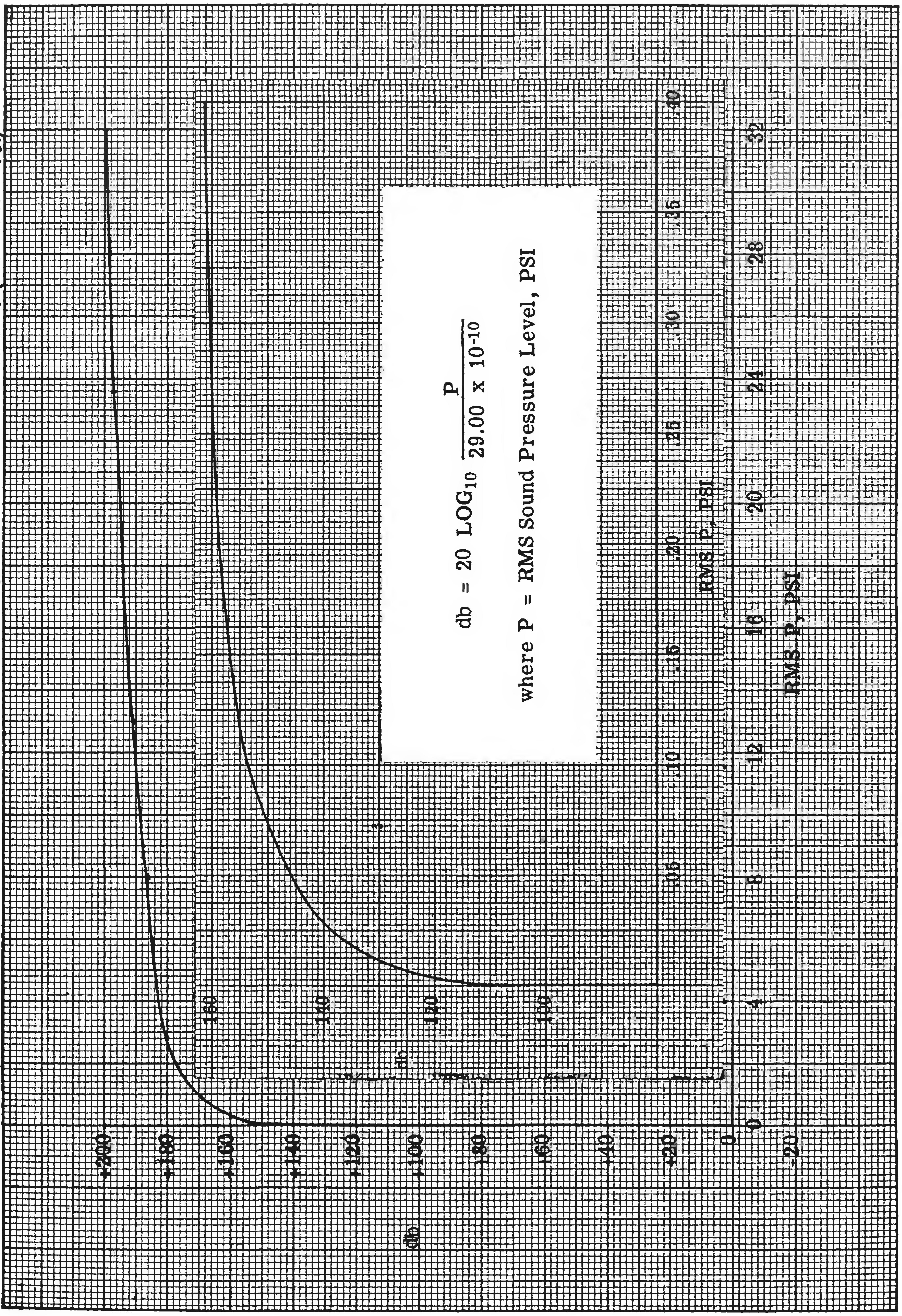


FIGURE 6.4 (C) SOUND PRESSURE DB ABOVE REFERENCE PRESSURE LEVEL OF 0.0002 MICROBARS (29.00×10^{-10} PSI)

FIGURE 6.5 FREQUENCY, WAVELENGTH, AND BAND NOMENCLATURE

Classification	Frequency Range	Wave Length Range
Very low frequency (VLF)	10-30 kc	30,000 to 10,000 meters
Low frequency (LF)	30-300 kc	10,000-1000 meters
Medium frequency (MF)	300-3000 kc	1000-100 meters
High frequency (HF)	3-30 mc	100-10 meters
Very high frequency (VHF)	30-300 mc	10-1 meters
Ultra high frequency (UHF)	300-3000 mc	100-10 cm
Super high frequency (SHF)	3000-30,000 mc	10-1 cm

Band Frequency, mc/sec	Wave Length, cm
P 225-350	133 - 77
L 390-1550	77 - 20
S 1550-5200	20 - 5.8
C 3900-6200	11.8 - 7.3
X 5200-10900	5.8 - 2.5
K 10900-36000	2.5 - 0.8
V 46000-56000	0.6 - 0.5
Q 36000-46000	0.8 - 0.6

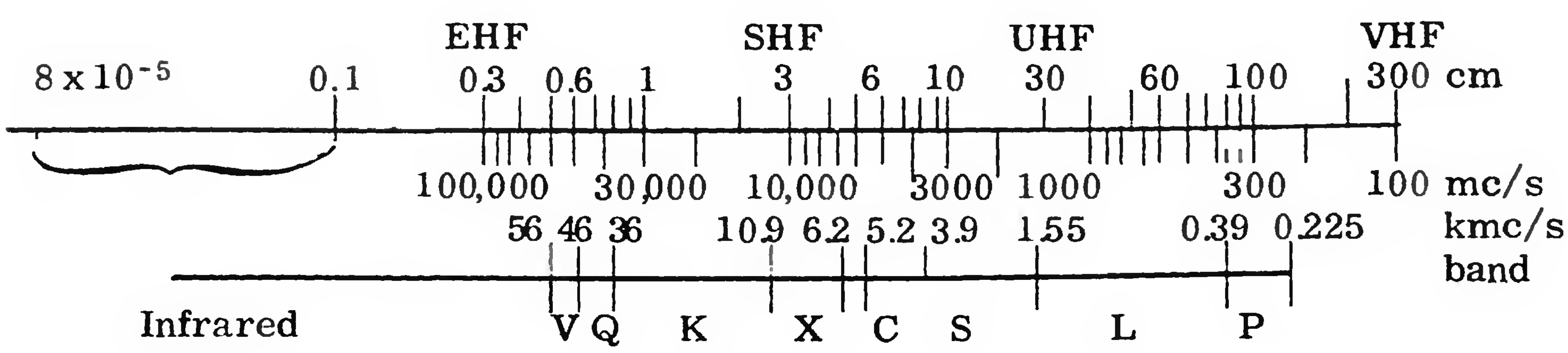
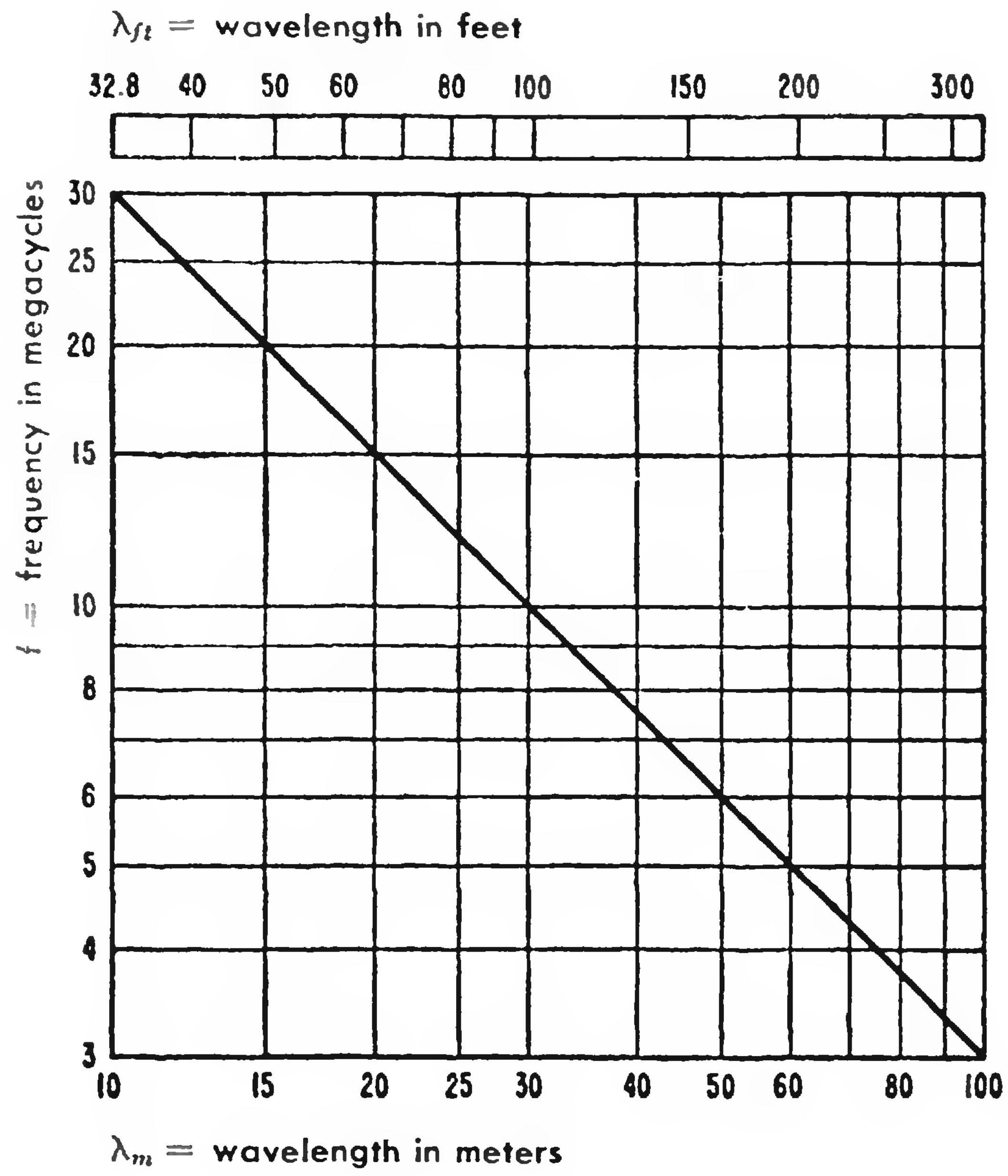


FIGURE 6.6 WAVELENGTH-FREQUENCY CONVERSION



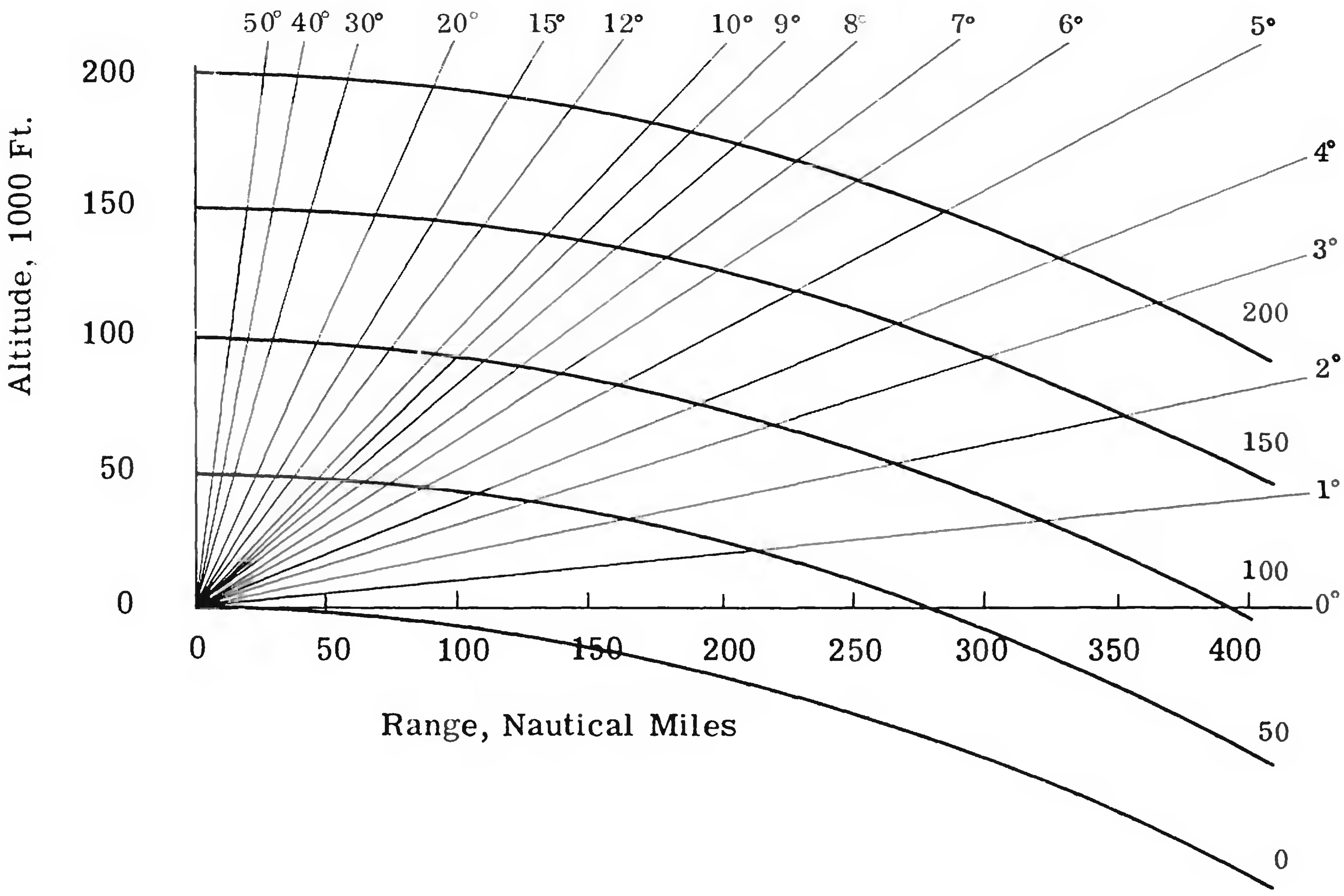
for frequencies from	multiply f by	multiply λ by
0.03 – 0.3 megacycles	0.01	100
0.3 – 3.0 megacycles	0.1	10
3.0 – 30 megacycles	1.0	1.0
30 – 300 megacycles	10	0.1
300 – 3,000 megacycles	100	0.01
3,000 – 30,000 megacycles	1,000	0.001
30,000 –300,000 megacycles	10,000	0.0001

FIGURE 6.7 RANGE COVERAGE CHART

Index of Refraction of Radio Waves

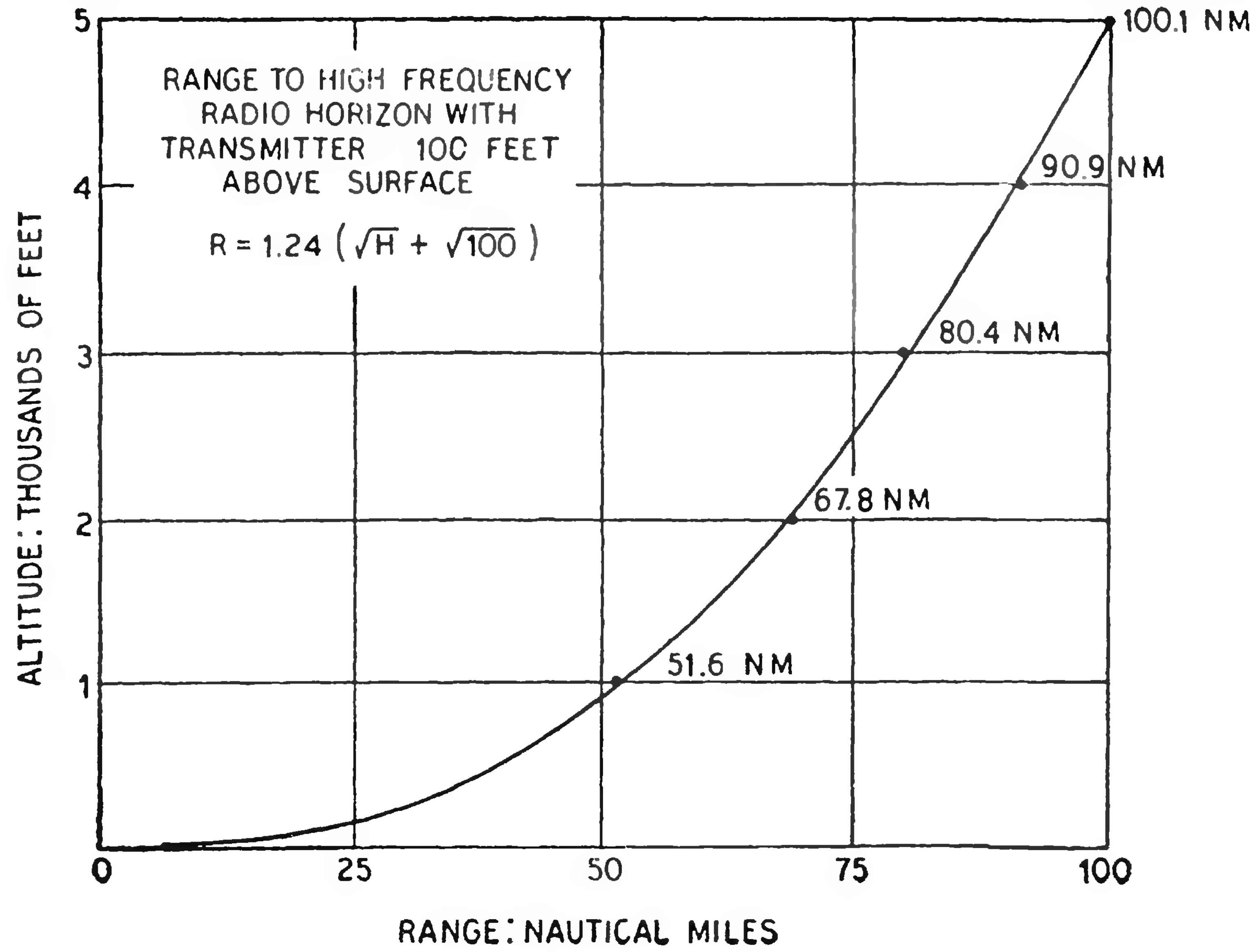
$$(n - 1) \times 10^6 = \frac{79p}{T} - \frac{11a}{T} - \frac{3.8 \times 10^5 a}{T^2}$$

where n = index of refraction of aid
p = barometric pressure in millibars
T = temperature in degrees Kelvin (273° + C)
a = water vapor pressure in millibars



Note: Curves corrected for "4/3 earth."
(Average atmospheric refractive index variation)

FIGURE 6.8 RANGE TO RADIO HORIZON AS A FUNCTION OF VHF-UHF RECEIVER ALTITUDE



RADAR RANGE

The theoretical maximum free-space range, R, of a radar using an isotropic common receiving and transmitting antenna, lossless transmission line, and a perfect receiver, may be found as follows:

λ = wavelength
A_t = effective area of transmitting aerial
A_r = effective area of receiving aerial
A_e = effective radar or echoing area of the target
G = power gain of transmitting aerial
$k = \frac{G\lambda^2}{A_t}$ - a constant for the particular type of transmitter aerial
P_t = peak transmitted power
P_m = minimum power required for detection

Transmitted pulse energy = P_t (in peak watts) X τ (in seconds)
Energy incident on target = $P_t \tau / A\pi R^2$ per unit area
Energy returned to antenna = $P_t \tau A_e / (4\pi R^2)^2$ per unit area
Energy at receiver input = $P_t \tau A_e \lambda^2 / (4\pi)^3 R^4$
Receiver input-noise energy = KT = 4.11 x 10^{21} joules.

Assuming that the receiver adds no noise, and that the signal is visible on the indicator when signal and noise energies are equal, the maximum range, R, is found to be:

$$R = \left[\frac{P_t \tau A_e \lambda^2}{(4\pi)^3 (KT)}\right]^{1/4} = \left[\frac{P_t K A_t A_r A_e}{P_m (4\pi)^2 \lambda^2}\right]^{1/4} = \left[\frac{P_t G A_e A_r}{P_m (4\pi)^2}\right]^{1/4}$$

Thus:

(i) Range is proportional to the fourth root of transmitter power.
(ii) Doubling P_t only increases range by about 20 per cent.
(iii) To double the range, P_t must be increased 16 times.
(iv) Range is increased by decreasing the wavelength. This is because the beam becomes narrower, and G is consequently increased.

FIGURE 6.9 THE RADAR RANGE EQUATION

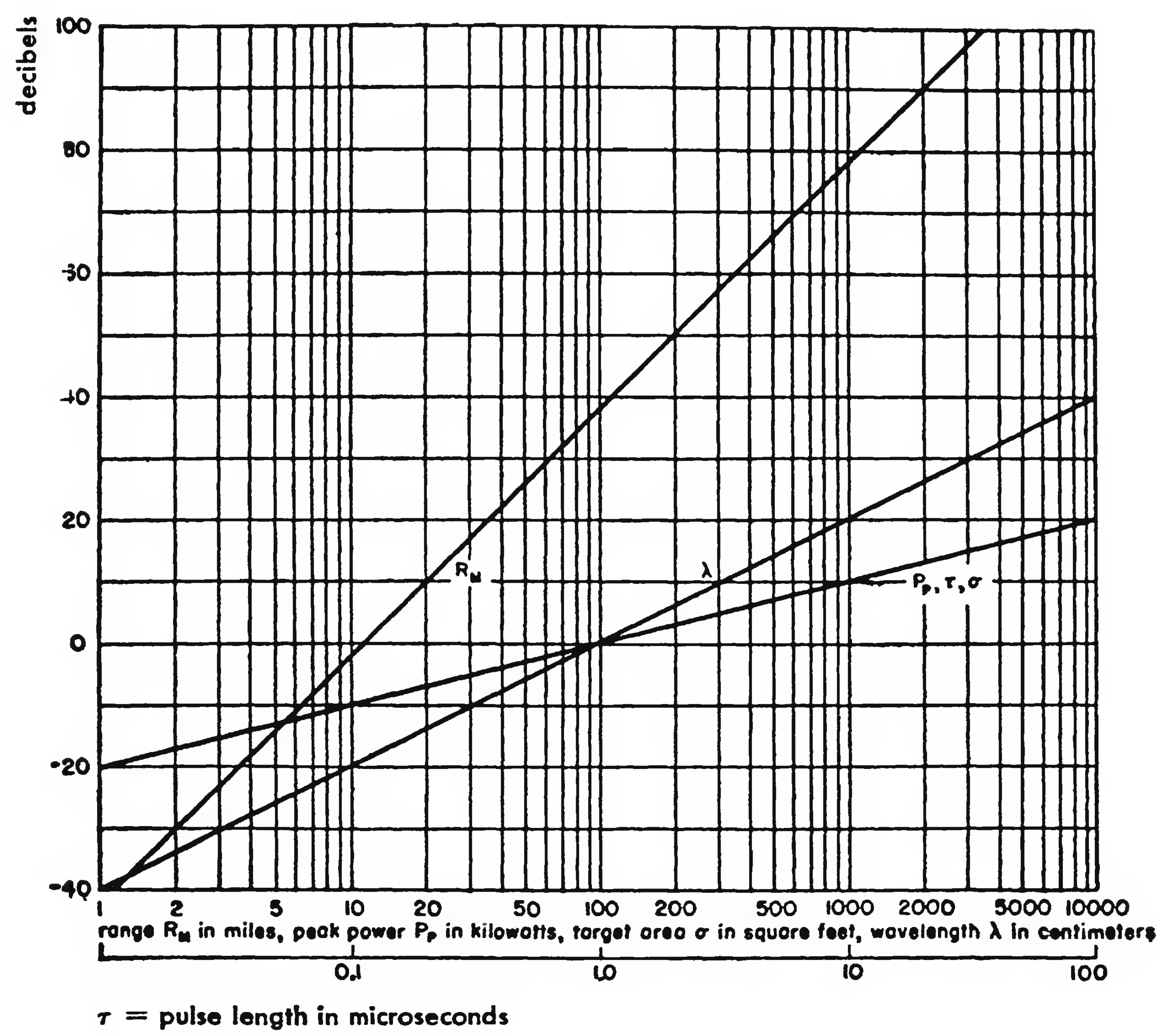
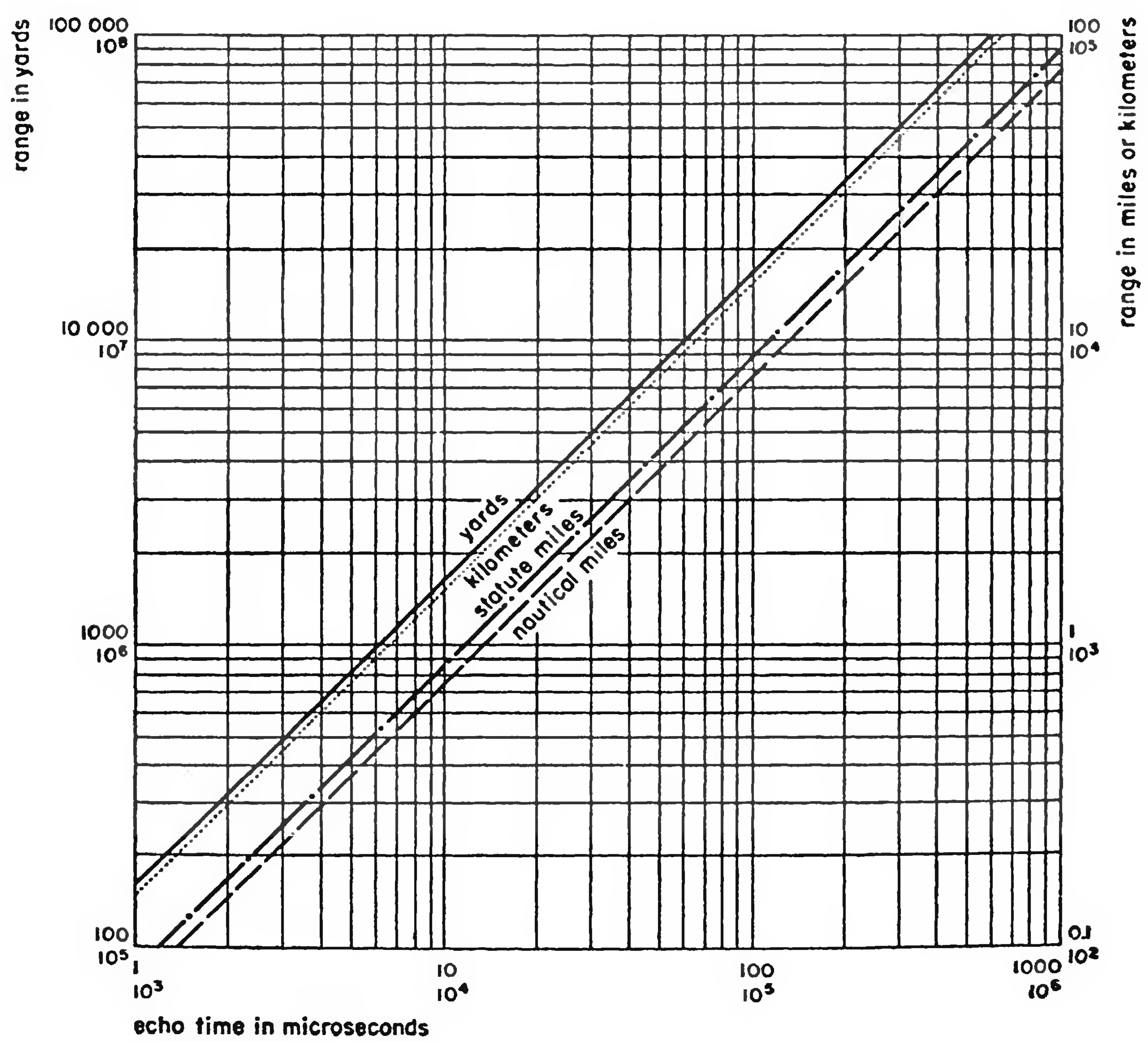


FIGURE 6.10 TIME BETWEEN TRANSMISSION AND RECEPTION OF A REFLECTED SIGNAL

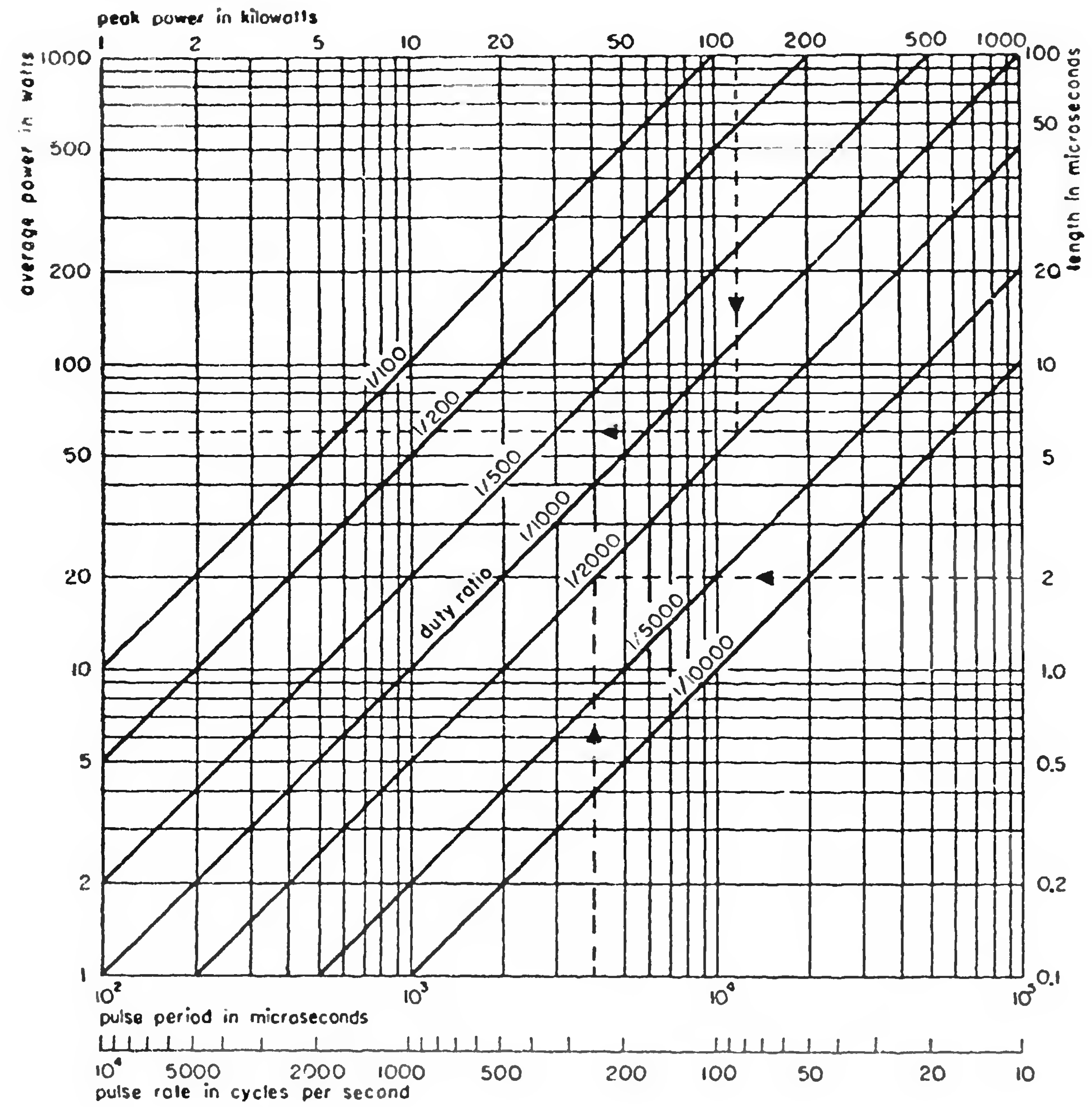


RADAR RANGE MEASUREMENT IN AIR

The time-equivalence to range in radar measurement:

1	microsecond corresponds to 149.85 meters or 163.88 yards
6.673	microseconds correspond to 1 kilometer
10.739	microseconds correspond to 1 statute mile
12.354	microseconds correspond to 1 nautical mile (6076.1 feet)

FIGURE 6.11 POWER-TIME RELATIONSHIPS FOR A RADAR TRANSMITTER



GROUND REFLECTION EFFECTS (RADAR)

For targets at low angular elevations, e.g., ships or low flying aircraft, rays reflected from the earth or sea interfere with the direct radar ray.

Eq. 6.17
$$R = \sqrt[8]{\frac{P_t k A_t A_e A_r 16\ \pi^2 h^4 H^4}{P_m\ \lambda^6}}$$

where R is the radar range and h and H are the heights above earth or sea of the radar aerial and target, respectively. This formula only applies provided R is much greater than $\sqrt{h + H}$, and is based on the assumption that perfect reflection is approximately correct for low values of angular elevation. It should be noted that, in these circumstances, the range is proportional to the eighth root of the transmitter power, which explains the difficulty of detecting low-flying aircraft at reasonably long ranges.

With narrow beams and angles of elevation such that ground reflections do not occur, the free space equation is applicable. This will be the case for most centimetric radars at elevations exceeding a few degrees.

FIGURE 6.12 RADAR DOPPLER FREQUENCY NOMOGRAPH

How to Use the Nomograph

The nomograph consists of three vertical axes upon which are respectively: Doppler frequency, radial velocity, and transmitted wavelength. The Doppler frequency corresponding to a given radial velocity is found by placing a straightedge so as to connect the known values of radial velocity. V_r, and transmitted wavelength, λ_t. The Doppler frequency is read on the left-lower axis. The proper scale to use is determined by noting which of the three columns of values on the λ_t-axis (A, B, or C) was used. The corresponding column is then used on the Doppler-frequency axis.

Examples of Use

Problem 1: A Doppler system with a transmitted wavelength of 10cm (3000Mc), is required to detect targets having radial velocities of from 100 to 1000-mph. What Doppler frequencies will be present in the system?

Solution: The straightedge is placed to connect 10cm under Column A of the λ_t-axis with 100mph on the radial-velocity axis. A value of 890cy is read under Column A of the Doppler-frequency axis. Again using Column A, the straightedge is placed to connect 10cm on the λ_t-axis with 1000mph on the center axis. A value of 8900cy is read from the Doppler-frequency axis. Thus, Doppler frequencies lying between 890 and 8900cy will be present in the system.

Problem 2: In an existing Doppler radar, the highest allowable Doppler frequency is 5000cy. If target speeds up to 1000 knots are anticipated, what must be the transmitted wavelength?

Solution: Find 5000cy on the Doppler-frequency axis (Column B). Using the straightedge, connect this value with 1000 knots on the center axis. A value of 20cm is read under Column B of the λ_t-axis. Hence, the radar transmitter should operate with a wavelength no shorter than 20cm (1500Mc).

$$f_D = \frac{89.4V}{\lambda_t} \text{ cycles}$$

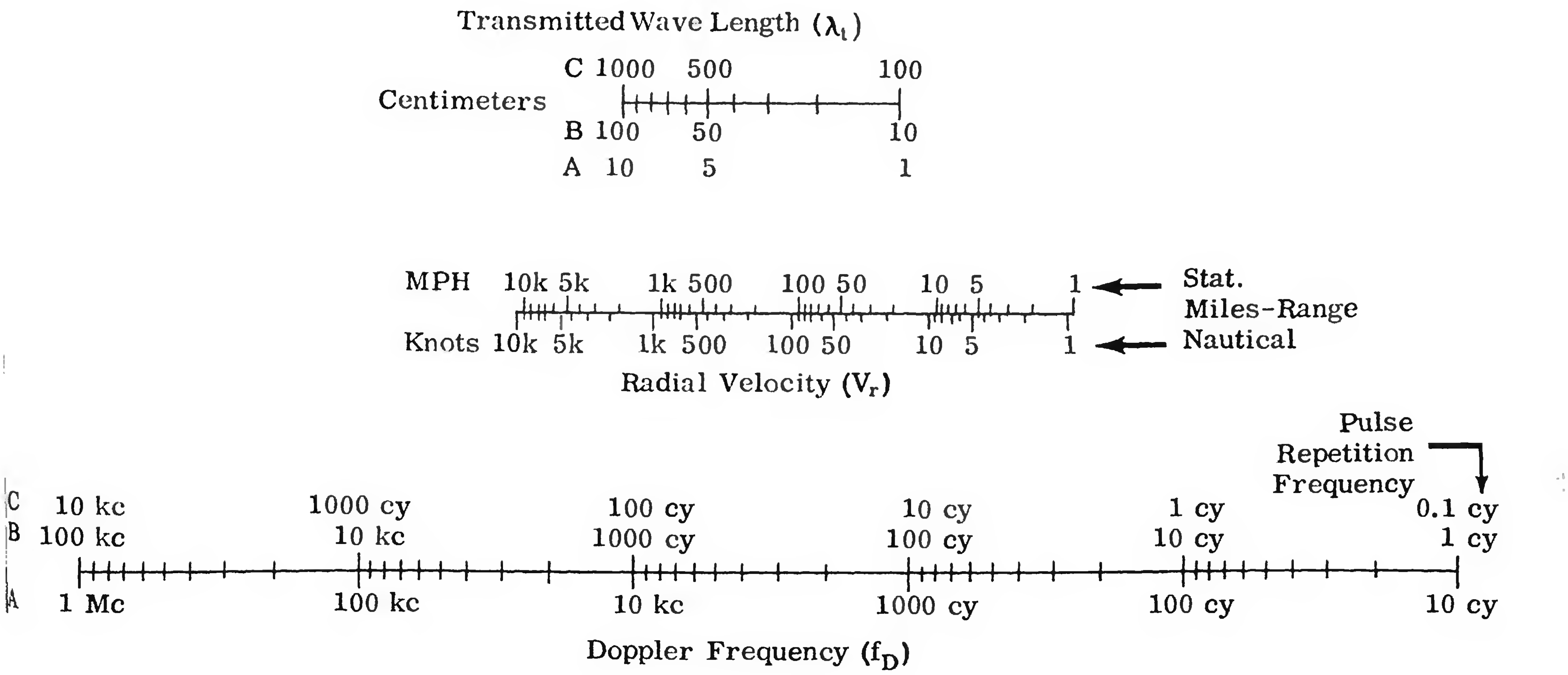
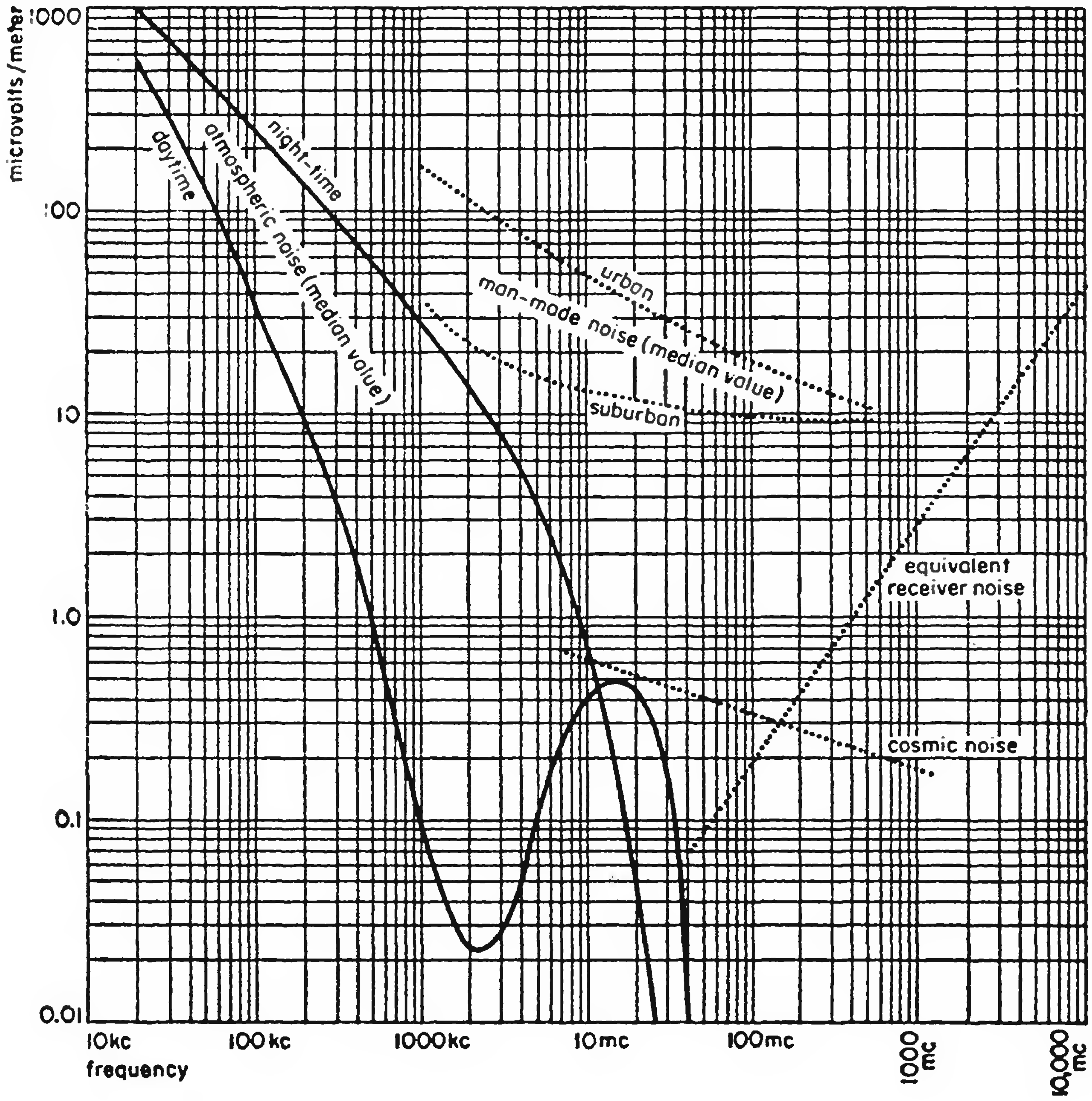


FIGURE 6.13 MAJOR SOURCES OF RADIO-FREQUENCY NOISE, SHOWING AMPLITUDES AT VARIOUS FREQUENCIES FOR THE U.S.A. AND REGIONS OF SIMILAR LATITUDE



1. All curves assume a bandwidth of 10 kilocycles/second.
2. Refer to Fig. 6.13(A) for converting man-made-noise curves to bandwidths greater than 10 kilocycles. For all other curves, noise amplitude varies as the square root of bandwidth.
3. The curve of receiver noise shows the field intensities required to equal the receiver noise assuming
   a. The use of a half-wave-dipole antenna.
   b. A receiver noise level greater than the ideal receiver level by a factor varying from 2 decibels at 50 megacycles to 9 decibels at 1000 megacycles.
4. Transmission-line loss is not considered in the calculations.
5. For antennas having a gain with respect to a half-wave dipole, equivalent noise-field intensities are less than indicated above in proportion to the net gain of the antenna-transmission line combination.

FIGURE 6.13 (A)

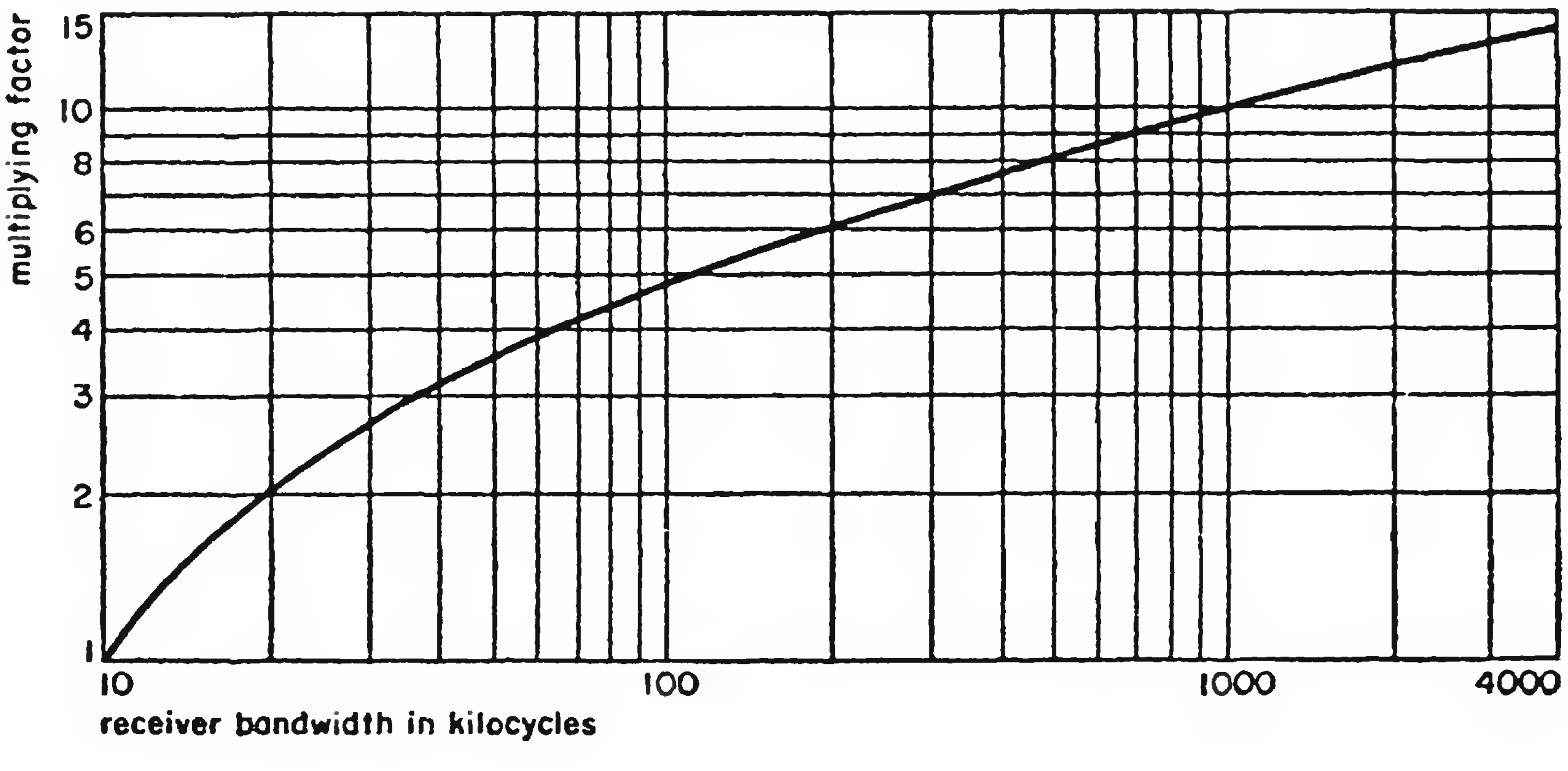


FIGURE 6.14 RANGE REQUIREMENTS FOR PATTERN MEASUREMENTS FOR FIELD $R = \frac{2D^2}{\lambda}$

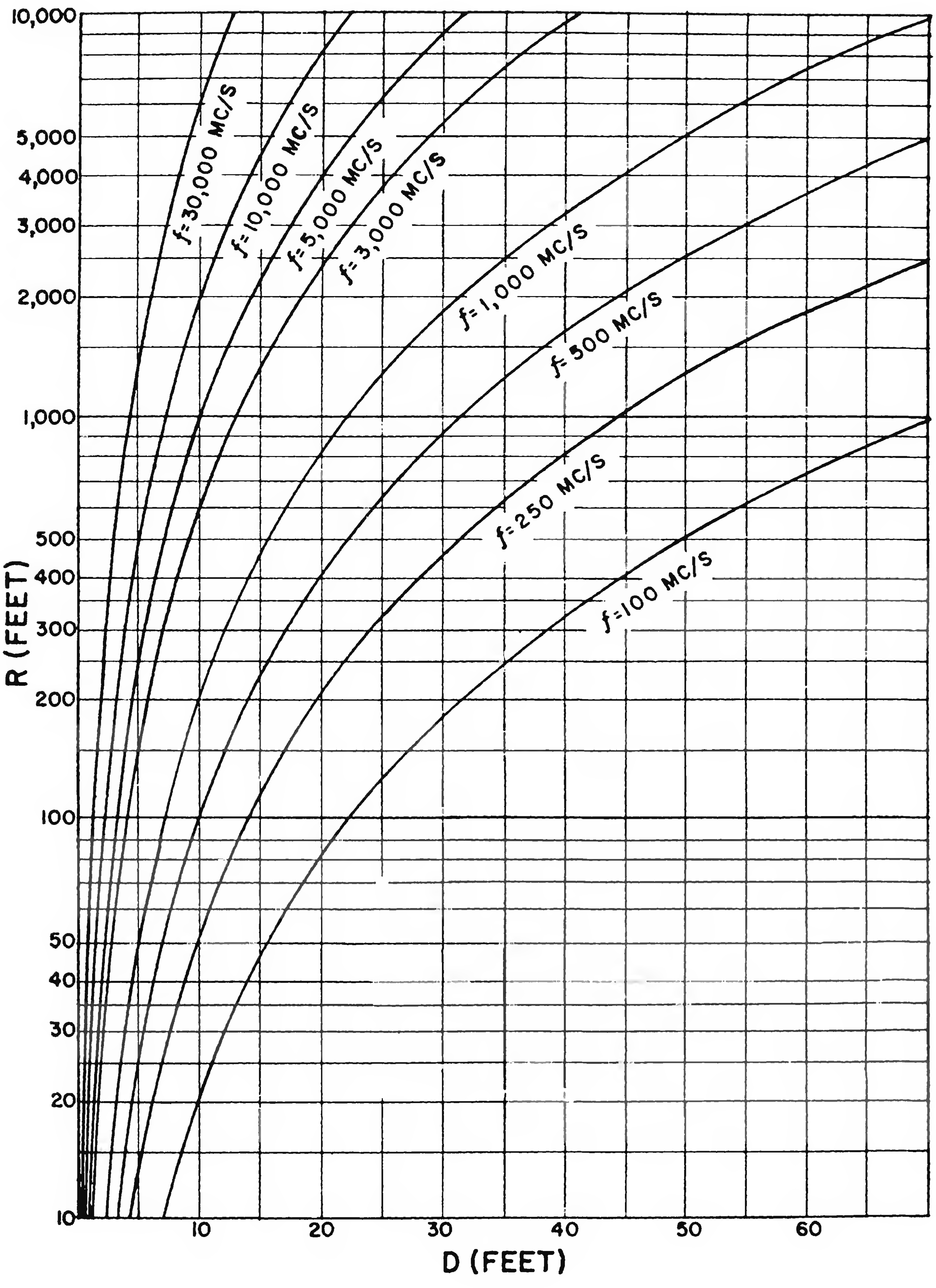
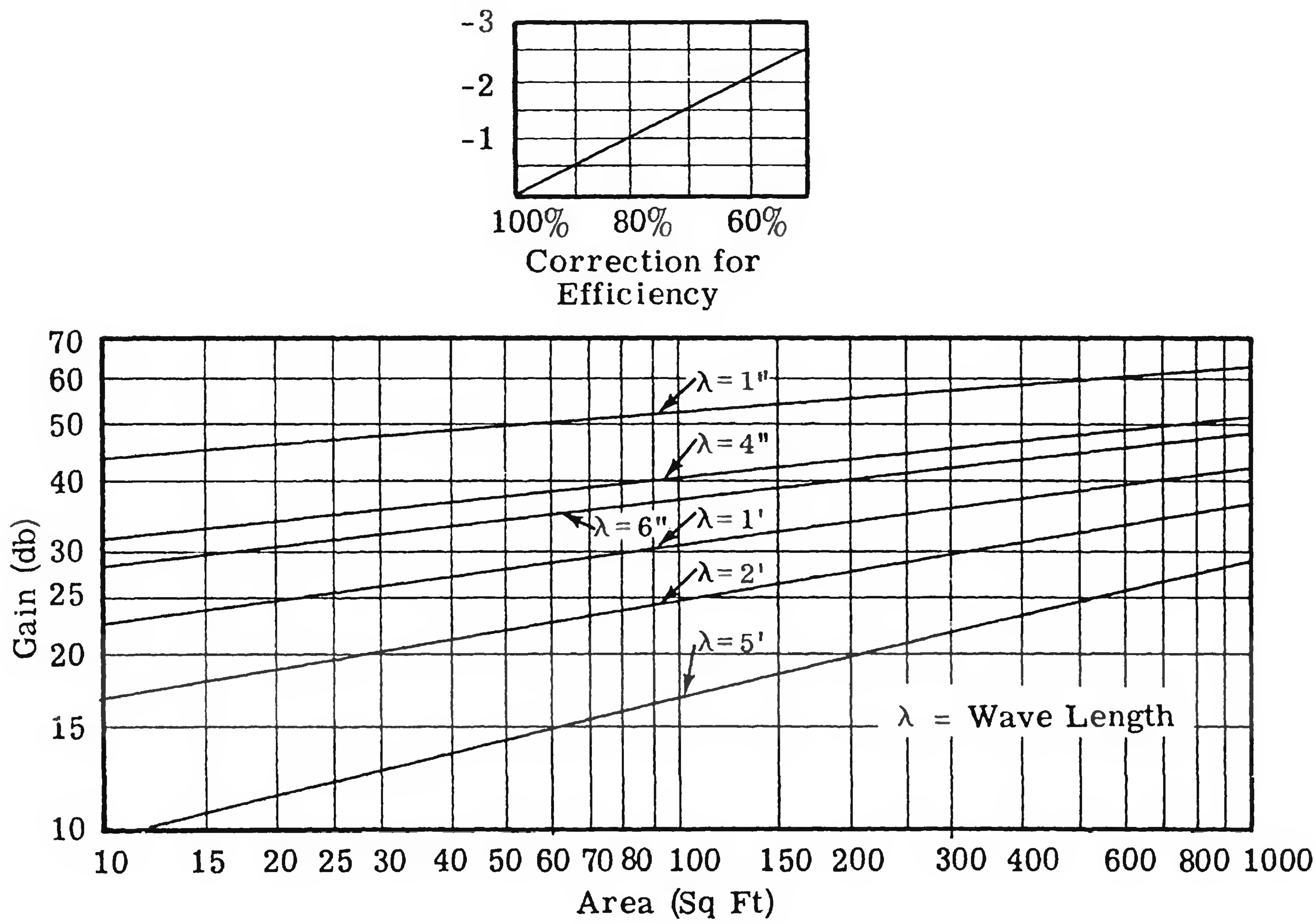


FIGURE 6.15 ANTENNA GAIN - WAVELENGTH - APERTURE RELATION

Radiator	Gain above Isotropic Radiator	Effective Area
Isotropic radiator	1	$\lambda^2/4\pi$
Infinitesimal dipole or loop	1.5	1.5 $\lambda^2/4\pi$
Half-wave dipole	1.64	1.64 $\lambda^2/4\pi$
Optimum horn (mouth area = A)	10 A/λ^2	0.81 A
Horn (maximum gain for fixed length) (mouth area = A)	5.6 A/λ^2	0.45 A
Parabola or metal lens	6.3 to 7.5 A/λ^2	0.5 to 0.6 A
Broadside array (area = A)	4π A/λ^2 (max)	A (max)
Omnidirectional stacked array (length = L, stack interval $\leqslant \lambda$)	$\approx 2L/\lambda$	$\approx L\ \lambda/2\pi$
Turnstile	1.15	1.15 $\lambda^2/4\pi$



The relation between the maximum gain G_0, the area of the aperture A, and the wave length λ:

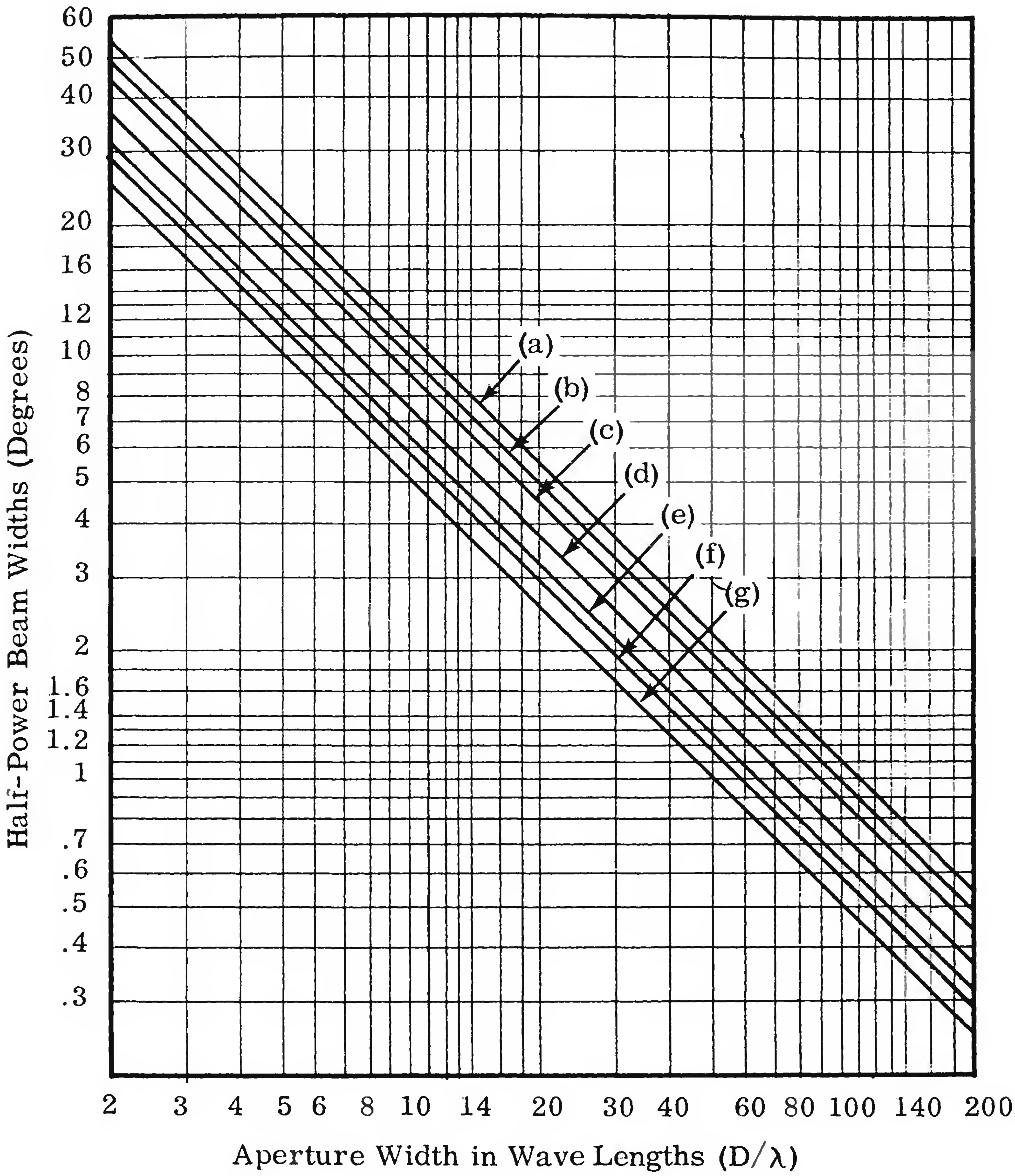
$$G_0 = \frac{4\pi A K_0}{\lambda}$$

The dimensionless factor K_0 is equal to 1 if the excitation is uniform in phase and intensity over the whole aperture; in actual antennas K_0 is often as large as 0.6 or 0.7 and is rarely less that 0.5.

FIGURE 6.16 ANTENNA HALF-POWER BEAM WIDTH VS APERTURE WIDTH

For a circular aperture the beam width in degrees:

$$\text{Approximately } \frac{70\,\lambda}{D}$$



Curve	Illumination Taper	Theoretical First Side Lobe Level
(a)	$(\text{Cosine})^4$	44.6 db
(b)	$(\text{Cosine})^3$	39.0 db
(c)	$(\text{Cosine})^2$	32.8 db
(d)	(Cosine)	25.8 db

Curve	Illumination Taper	Theoretical First Side Lobe Level
(e)	Average antenna	20.0 db
(f)	Uniform	17.6 db
(g)	Uniform	13.2 db

Curves (a) thru (f) are for circular or elliptical apertures. Curve (g) is for rectangular aperture.

FIGURE 6.17 POWER DENSITY AT VARIOUS DISTANCES FROM A HALF-WAVE DIPOLE

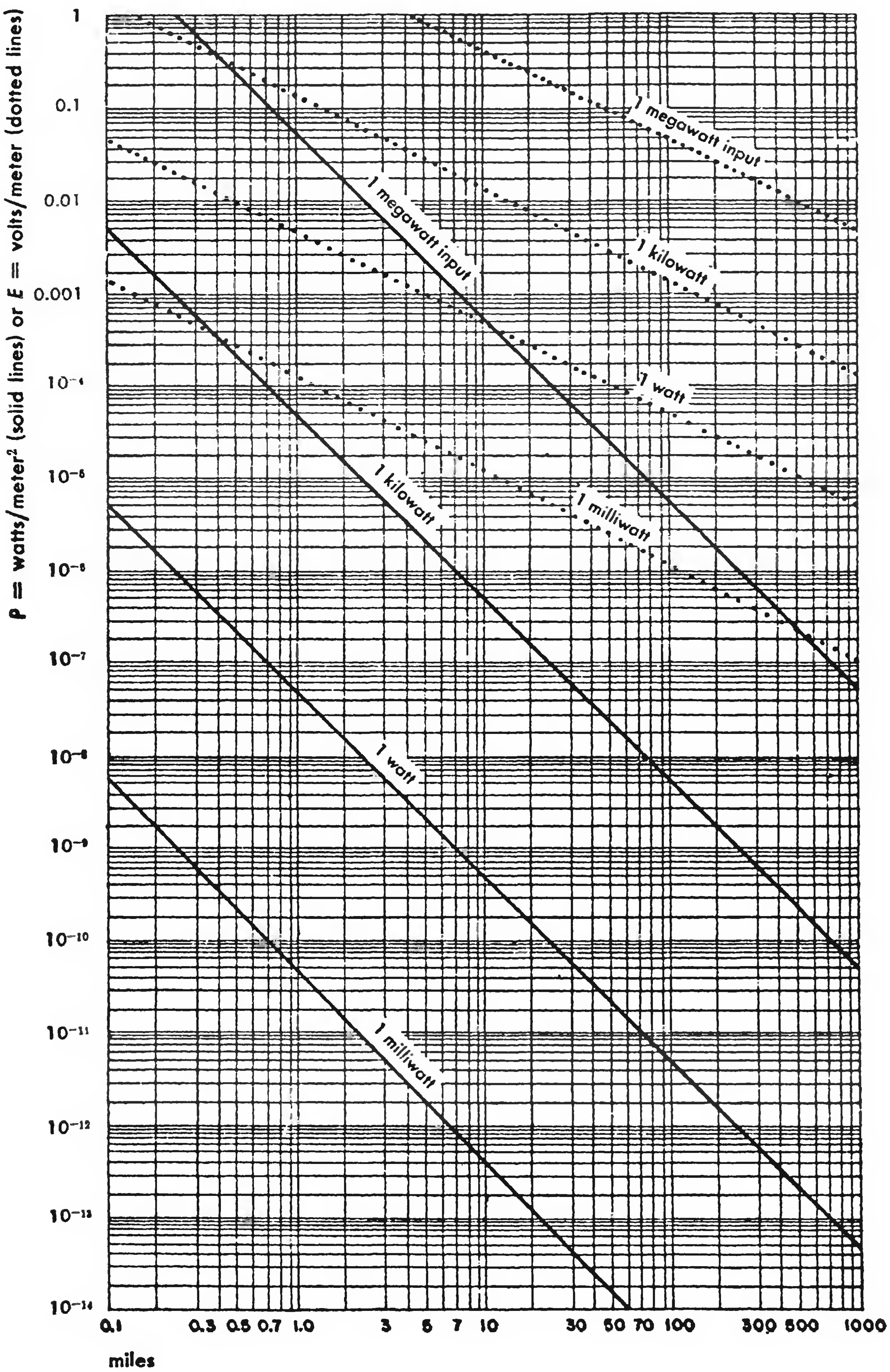


FIGURE 6.18 THEORETICAL VALUES OF ATTENUATION BY RAIN AND FOG

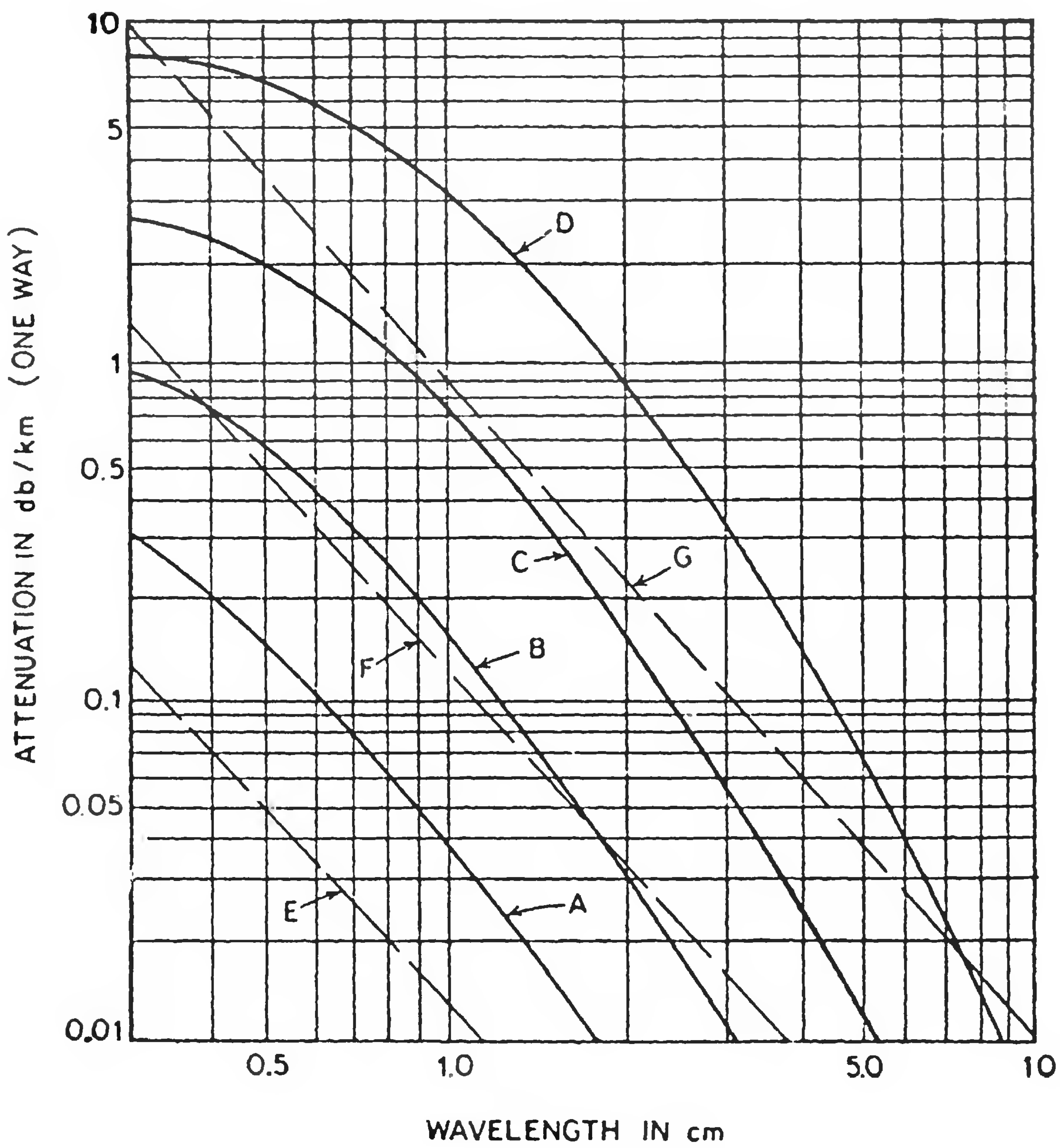
Solid curves show attenuation by rain of the following intensities:

A	Drizzle	0.25 mm/hr
B	Light Rain	1.0 mm/hr
C	Moderate Rain	4.0 mm/hr
D	Heavy Rain	16.0 mm/hr

Dashed curves show attenuation by fog or cloud of the following intensities:

E	Visibility	2000 ft	0.032 g/m^3
F	Visibility	400 ft	0.32 g/m^3
G	Visibility	100 ft	2.3 g/m^3

(By permission from Propagation of Short Radio Waves, by Kerr. Copyright 1951, McGraw-Hill Book Co., Inc.)



Eq. 6.18 Plane of Polarization of a Radio Wave

Determined by convention to be the direction of the electric field with respect to the earth's surface.

For horizontal polarization

$$R_h = \frac{\sin\psi - \sqrt{\epsilon - \cos^2\psi}}{\sin\psi + \sqrt{\epsilon - \cos^2\psi}}$$

For vertical polarization

$$R_v = \frac{\epsilon\sin\psi - \sqrt{\epsilon - \cos^2\psi}}{\epsilon\sin\psi + \sqrt{\epsilon - \cos^2\psi}}$$

where ϵ = the complex relative dielectric constant
ψ = grazing angle, (angle of incidence = $90^\circ - \psi$)

Factors affecting choice of polarization:

(a) The extent of reinforcement by reflection of the maxima
(b) The extent of signal cancellation in the minima
(c) The effects of surface roughness
(d) The effects of the foregoing on the manner in which the signal is treated by a specific system

Reflection Coefficient for Horizontal Polarization. At the point of reflection, of an electromagnetic wave, the ratio of any scalar quantity in the reflected wave to the same quantity in the incident wave is defined as the reflection coefficient of the reflecting medium. Thus defined, the reflection coefficient can be different for the various components of the field. The reflection coefficient R, considering the electric vectors, is equal to E_r/E_i.

ϵ is the complex relative dielectric constant of the reflecting medium. These equations indicate that the magnitude of the reflected electric vector E_r is equal to RE_i and leads or lags it in phase, as the case may be, by a computable amount.

ABSORPTION OF ELECTROMAGNETIC WAVES

The absorption of electromagnetic waves in an isotropic, gaseous medium may be obtained by assuming a uniform distribution in a region small compared to the flame dimensions.

Absorption loss, db/meter = $-8.68\omega\mu^{1/2}$ k where k, the index of absorption is determined from

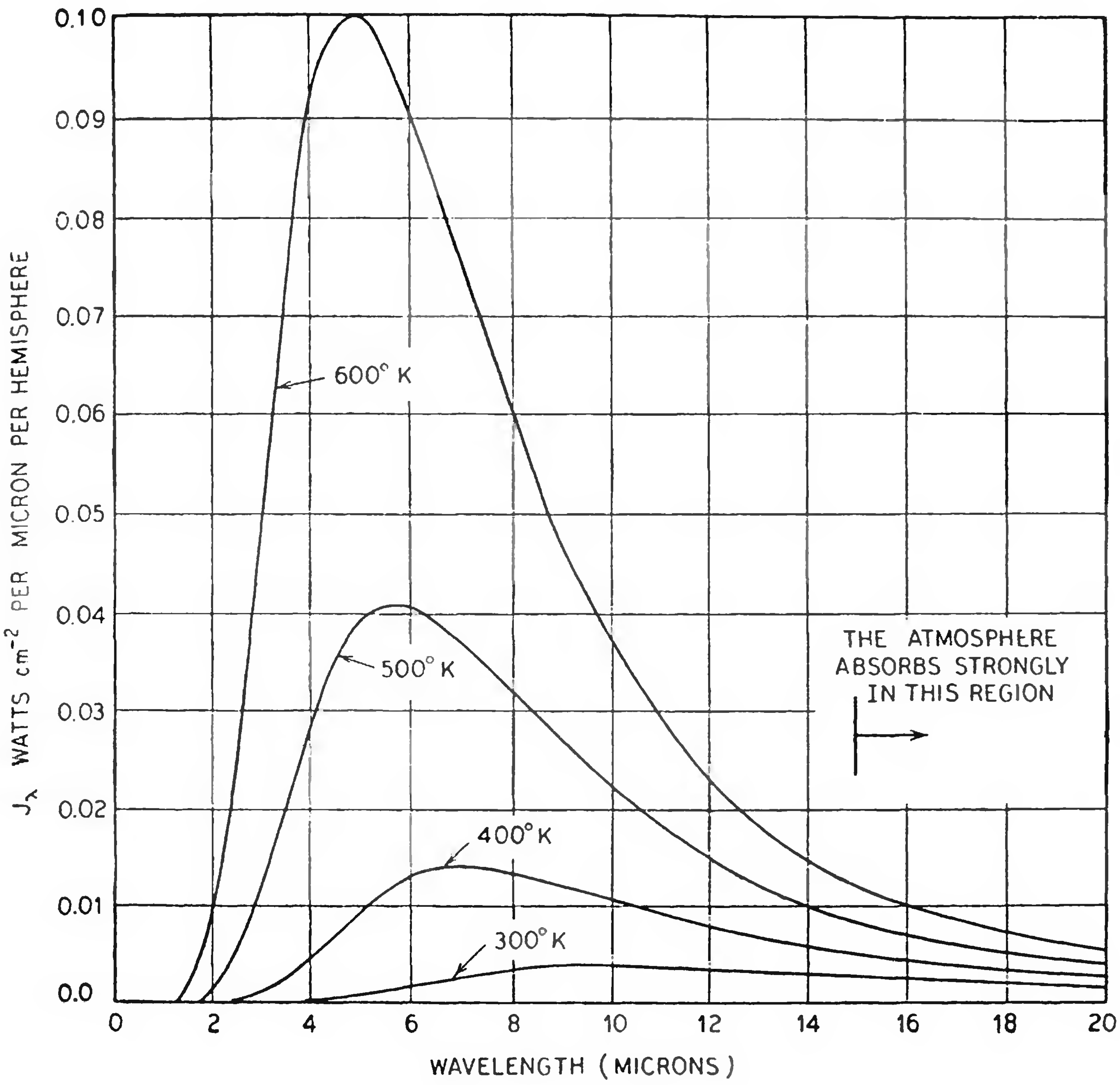
Eq. 6.19
$$k^2 = 1/2\left[-\left(\epsilon - \frac{4\pi\sigma_i}{\omega}\right) + \sqrt{\left(\epsilon - \frac{4\pi\sigma_i}{\omega}\right)^2 + \left(\frac{4\pi\sigma_r}{\omega}\right)^2}\right]$$

and the relative phase shift for the same signal may be expressed as: Relative phase shift = $\omega\mu^{1/2}n$ (in rad/sec.)

$$n^2 = 1/2\left[\left(\epsilon - \frac{4\pi\sigma_i}{\omega}\right) + \sqrt{\left(\epsilon - \frac{4\pi\sigma_i}{\omega}\right)^2 + \left(\frac{4\pi\sigma_r}{\omega}\right)^2}\right]$$

and where μ = the permeability of the medium
ϵ = the dielectric constant of the medium

FIGURE 6.19 SPECTRAL DISTRIBUTION OF ENERGY FOR PERFECT EMITTERS



Emissive Power

The total emissive power of a surface of unit area is the amount of energy of all wavelengths radiated per second into a solid angle of 2π steradians, or a hemisphere. It is given by the Stefan-Boltzmann Law,

Eq. 6.20
$$E = \epsilon\sigma T^4$$

Where E = total emissive power (watts cm^{-2} per hemisphere)
σ = the Stefan-Boltzmann constant (5.7×10^{-12} watt cm^{-2} deg^{-4})
T = absolute temperature (°K)
ϵ = total emissivity of the surface

the emissivity is unity for a black body, or perfect radiator.

Intensity of Radiation

Intensity of radiation of a surface is the emissive power per steradian normal to the surface

$$I = \frac{E}{\pi} = \frac{\epsilon\sigma T^4}{\pi}$$

sometimes called the steradiancy. This relationship applies for surfaces which obey the Lambert cosine law that the emissive power at any angle with the

normal is proportional to the cosine of that angle. It is not strictly obeyed by many actual materials, but deviations are small and rarely of sufficient significance to justify tedious measurement for the purposes of practical applications.

Emissivities (Normal)

The emissivity of an opaque material is a surface property. Any alteration of the surface will change it: for example, roughening a metallic surface. The emissivity can only be considered to be a physical property of the material when it is measured for an opaque polished specimen. Composite materials such as paint films, anodized aluminum, or shiny mirrors coated with thin liquer will possess emissivities which depend on thickness of film, nature of the organic vehicle, and so on. Excluding polished metals and restricting attention to ordinary earth temperature, say, 273°K to 500°K, many objects are esentially black. The earth, foliage, water and ice, bricks and stones, granular paint films of whatever color, cloth, glass, wood, and the human skin are essentially black so far as their emission of radiation at ordinary temperatures is concerned. (See Fig. 6.20).

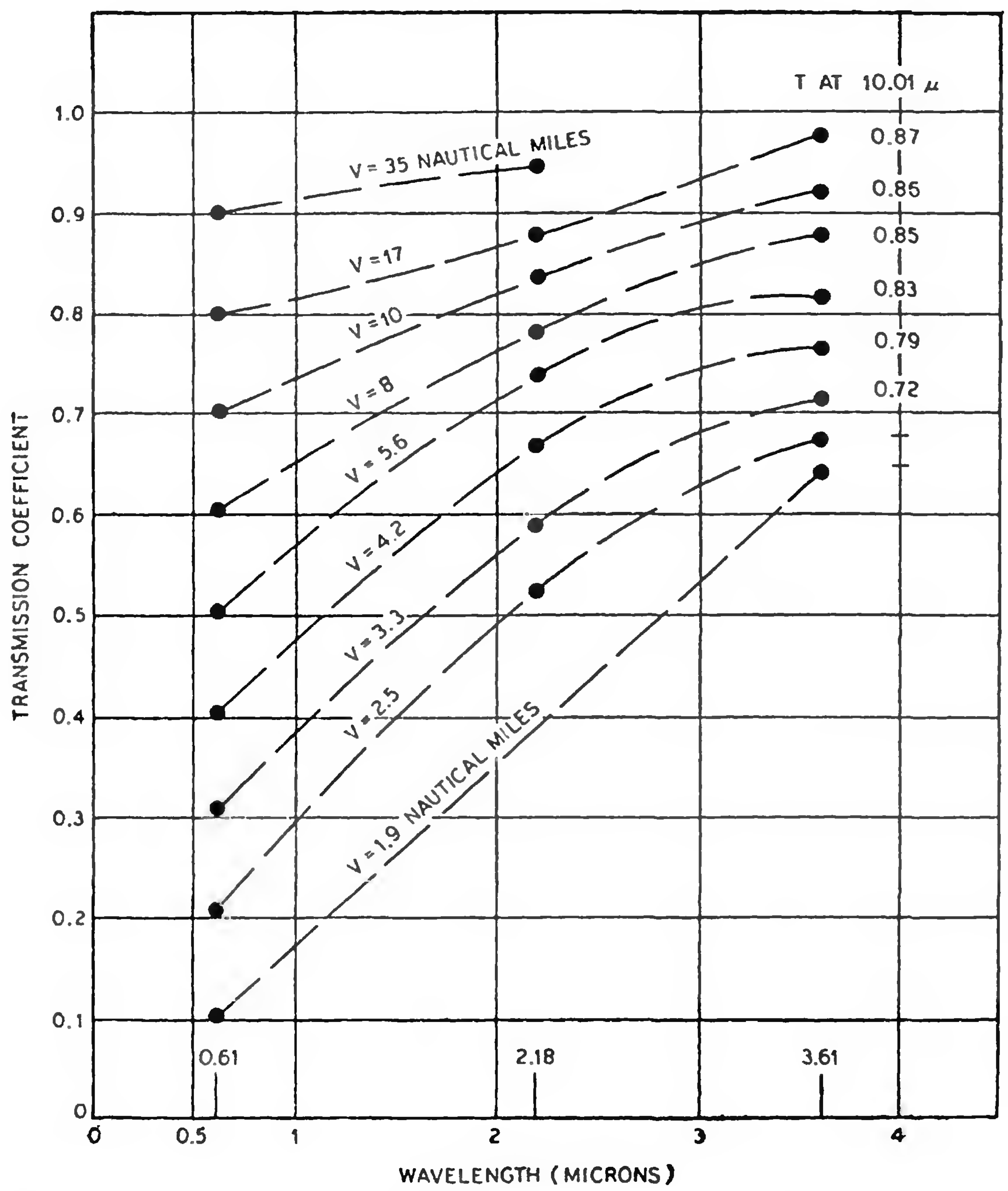
FIGURE 6.20 TOTAL EMISSIVITY VALUES FOR SELECTED MATERIALS, METALS AND GLASSES

Material	Condition	At 100°C/212°F	At 100°C/300°F	At 320°C/608°F	At 500°C/932°F
Alleghany metal	No. 4 polish	0.13			
Alleghany Alloy No. 66	Polished	0.11			
Aluminum	Commercial Sheet	0.09			
Aluminum	Commercial Sheet rough	0.07			
Aluminum	Polished	0.095	0.053	0.063	
Aluminum	Rough polish	0.18			
Aluminum foil		0.04			
Aluminum paint		0.29			
(special types)		0.18		0.18	0.18
Beryllium		0.61	0.61	0.61	0.61
Brass	Polished	0.05 to 0.059			
Brass — oxidized		0.07	0.61	0.6	0.59
Carbon	Rough plate	0.77		0.77	0.72
Carbon, graphitized	Rough plate	0.76		0.75	0.71
Chromium	Polished	0.075			
Copper	Polished	0.052 to 0.04	0.03	0.03	
Copper — nickel	Polished	0.059			
Covex D (glass)	3.40 m. thick	0.83		0.90	0.91
Fused quartz	1.96 m. thick	0.775		0.76	0.67
Granular pigment	Any color	0.90 to 0.94			
Iron	Dark gray surface	0.31			
Iron	Roughly polished	0.27			
Lampblack	Rough deposit	0.84			0.78
Molybdenum	Polished	0.071			
Nickel	Polished	0.072			0.13
Nickel — silver	Polished	0.135			
Nonex (glass)	1.57 m. thick	0.835		0.87	0.82

FIGURE 6.20 TOTAL EMISSIVITY VALUES FOR SELECTED MATERIALS, METALS AND GLASSES (cont.)

Material	Condition	At 100°C/212°F	At 100°C/300°F	At 320°C/608°F	At 500°C/932°F
Radiator paint, white	Clean	0.79			
Radiator paint, cream	Clean	0.77			
Radiator paint, black	Clean	0.34			
Radiator paint, bronze	Clean	0.51			
Silver	Polished	0.052 to 0.02	0.02	0.03	0.04
Stainless steel	Polished	0.074 to 0.09			
Steel	Polished	0.066			
Steel	Cold rolled, clean	0.08	0.60		
Steel	Scrubbed with steel wool	—	0.46		
Steel	Pickled in HCL	—	0.35		
Steel	Buffed bright	—	0.11		
Tin	Polished	0.069			
Tin	Commercial coat	0.084			
Titanium	Commercial coat	0.31	0.31	0.31	0.31
Tungsten	Polished Coat	0.066			
Zinc	Commercial Coat	0.31		0.11	

FIGURE 6.21 TRANSMISSION COEFFICIENT VS. WAVELENGTH



Transmission of 2000 yd of haze in the red and in the infrared windows at 2.18μ and 3.61μ. (The state of haziness is specified by the transmission at 0.61μ and also by visual detection ranges V noted on the curves.)

Power Absorbed by a Target

The power absorbed by a target for reradiation is the product of the electromagnetic radiation density and the target cross section.

Eq. 6.22
$$P = \frac{P_t G_t \sigma}{4\pi D^2}$$

This is now isotropically reradiated and the power density at a receiver at the same position as the transmitter is

$$P_r = \frac{P_t G_t \sigma}{(4\pi D^2)\ (4\pi D^2)}$$

The received power is:

$$P_r = \frac{P_t G_t \sigma A_r}{(4\pi D^2)^2}$$

The attenuation is:

If the earth is the target, as for an altitude fuze, and it is assumed that the earth is a diffuse reflector, the attenuation law is given approxi mately by

$$\frac{P_r}{P_t} = \frac{\rho A_r}{\pi D^2} \quad \text{for continuous operation}$$

where ρ describes the complex behavior of the ground as a reflector,

If the signal is pulsed, it may obey a law which reflects the fact that, at certain altitudes, the pulse length is too short to illuminate all the ground within the beam simultaneously.

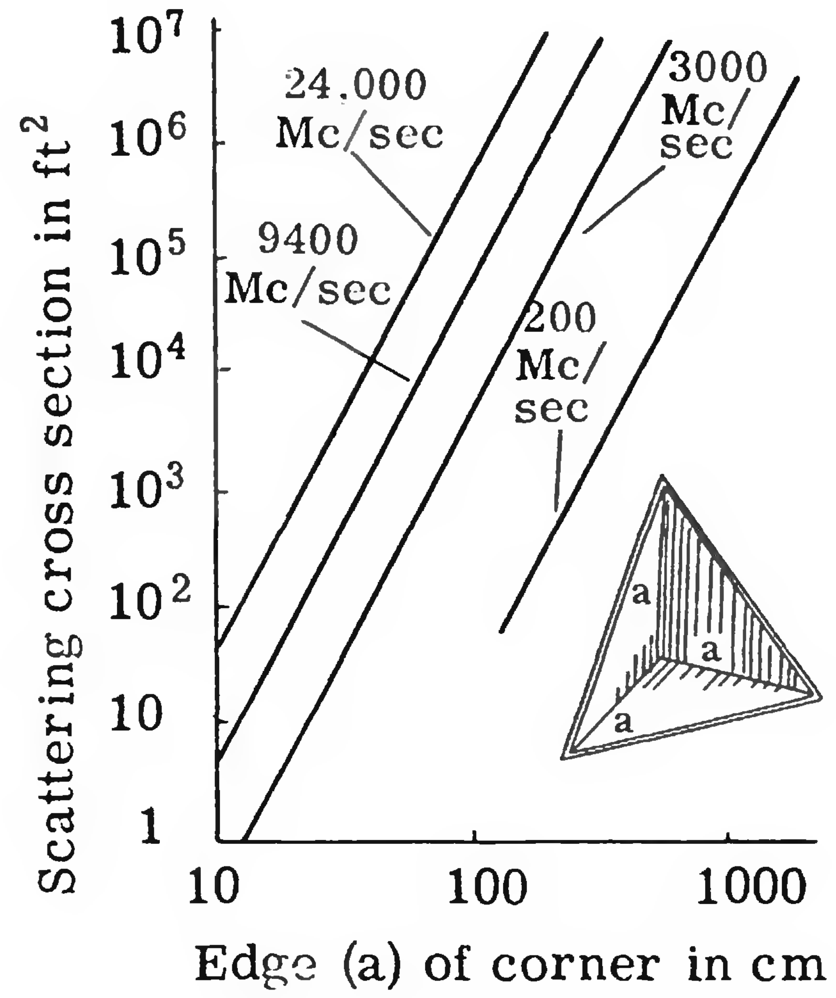
$$\frac{P_r}{P_t} = \frac{G_t \rho \tau c A_r}{8\pi^2 D^3}$$

where p is the ground behavior factor, τ is the pulse length, and c is the velocity of light.

FIGURE 6.22 TARGET ECHOING AREA

Tuned $\lambda/2$ dipole	$0.22\lambda^2$
Small sphere with radius = a, where $a/\lambda < 0.15$	$9\pi a^2 (2\pi a/\lambda)^4$
Large sphere with radius = a, where $a/\lambda > 1$	πa^2
Corner reflector with one edge = a (maximum)	$4\pi a^4/3\lambda^2$
Flat plate with area = A (normal incidence)	$4\pi A^2/\lambda^2$
Cylinder with radius = a, length = L (normal incidence)	$2\pi L^2 a/\lambda$
Small airplane (AT-11)	200 feet^2
Large airplane (B-17)	800 feet^2
Small cargo ship	1,500 feet^2
Large cargo ship	160,000 feet^2

FIGURE 6.23 MAXIMUM SCATTERING CROSS SECTION OF TRIANGULAR CORNER REFLECTOR



FM/FM MISSILE TELEMETERING SYSTEM

The standard missile telemetering system in use today was established by RDB (DOD).* The systems are of the frequency division multiplex type. The RF carrier is modulated by a group of subcarriers, each of a different frequency, and the subcarriers are frequency modulated by the characteristics of the intelligence to be transmitted. One or more of the subcarriers may be modulated by a time multiplex or commutation scheme to provide a greater number of data channels. A system error of ± 2% is feasible excluding transducer error and ± 1% can be obtained under carefully controlled conditions.

Characteristics of the Carrier

Two frequency bands are available (216 - 235 mcs; 270 - 280 mcs). Specific frequency assignments must be obtained from appropriate test ranges or the FCC.

The carrier may be frequency modulated (FM) or phase modulated (PM). The maximum RF deviation is ± 125 kcs, and a maximum of 100 watts power is allowed. Spurious radiation signals are held 60 db or more below the power level of the fundamental.

Subcarrier Bands

Characteristics are given in Fig. 6.24.

Commutation

A variety of commutation schemes may be used, but some restrictions must be observed:

1. Certain commutation rates must not be exceeded. (See Fig. 6.25).
2. If automatic channel separation is to be used, the commutated signal must have a definite pattern of time sequencing.

* Telemetry Standards for Guided Missiles, IRIG Doc. No. 103-56.

FM/FM MISSILE TELEMETERING SYSTEM (cont.)

3. Conservative values for sample rate (Fig. 6.25) are such as to give a minimum error due to the switching transient (≃ 0.5%) during the last half of the cycle.

4. Minimum duration samples (Fig. 6.25) are 25% of the conservative values. Their use requires deletion of the low-pass filters in the recording equipment and replacement with units with cutoff frequencies about four times the recommended frequency response.

5. When automatic decommutation is planned, sampling must be in accordance with Fig. 6.26.

Note: These standards may not necessarily agree with Military Specification No. MIL-T-26985 (USAF), 2 March 1956.

FIGURE 6.24 SUBCARRIER BANDS

Band	Center Frequency (cps)	Lower Limit (cps)	Upper Limit (cps)	Maximum Deviation (percent)	Frequency Response* (cps)	Maximum Frequency Response (cps)
1	400	370	430	±7.5	6.0	30
2	560	518	602		8.4	40
3	730	675	785		11.0	55
4	960	888	1,032		14.0	70
5	1,300	1,202	1,398		20.0	100
6	1,700	1,572	1,828		25.0	125
7	2,300	2,127	2,473		35.0	175
8	3,000	2,775	3,225		45.0	225
9	3,900	3,607	4,193		59.0	295
10	5,400	4,995	5,805		81.0	405
11	7,350	6,799	7,901		110.0	550
12	10,500	9,712	11,288		160.0	800
13	14,500	13,412	15,588		220.0	1,100
14	22,000	20,350	23,650		330.0	1,650
15	30,000	27,750	32,250		450.0	2,250
16	40,000	37,000	43,000		600.0	3,000
17	52,500	48,560	56,440		790.0	3,950
18	70,000	64,750	75,250		1,050.0	5,250
A**	22,000	18,700	25,300	±15.0	660.0	3,300
B	30,000	25,500	34,500		900.0	4,500
C	40,000	34,000	46,000		1,200.0	6,000
D	52,500	44,620	60,380		1,600.0	8,000
E	70,000	59,500	80,500		2,100.0	10,500

* Frequency response given is based on maximum deviation and a deviation ratio of five. A ratio as low as one can be used at the expense of increased harmonic distortion or crosstalk.

** Bands A through E are optional and may be used by omitting adjacent bands as follows:

Bands Used	Omit Bands
A	15 and B
B	14, 16, A, and C
C	15, 17, B, and D
D	16, 18, C, and E
E	17 and D

Note: In the process of magnetic tape recording of the above listed subcarriers at a receiving station, provision may also be made to record a tape speed control tone and tape speed error compensation signals are specified in the Magnetic Tape Recorder/Reproducer Standards. The speed control tone frequency is 17,000 cps. The compensation signal frequencies are 50,000 cps and 100,000 cps at tape speeds of 30 and 60 inches per second respectively.

Separation of center frequencies ≃ 1.3 to 1 (except between 14.5 and 22K)

FIGURE 6.25 COMMUTATION RATES - UNSEPARATED DATA

Band	Center Frequency (cps)	Sample Duration (milliseconds)		Commutation Rate* (samples per second)	
		Conservative Values	Minimum Values	Conservative Values	Maximum Values
1	400	670	170	1.5	6
2	560	480	120	2.1	8.4
3	730	370	91	2.7	11
4	960	280	70	3.6	14
5	1,300	210	51	4.9	20
6	1,700	160	39	6.4	25
7	2,300	120	29	8.6	35
8	3,000	89	22	11	45
9	3,900	68	17	15	59
10	5,400	49	12	20	81
11	7,350	36	9.1	28	110
12	10,500	25	6.4	39	160
13	14,500	18	4.6	55	220
14	22,000	12	3.0	83	330
15	30,000	8.9	2.2	110	450
16	40,000	6.7	1.7	150	600
17	52,500	5.1	1.3	200	790
18	70,000	3.8	0.95	260	1,050
A	22,000	6.1	1.5	170	660
B	30,000	4.4	1.1	230	900
C	40,000	3.3	0.83	300	1,200
D	52,500	2.5	0.63	390	1,600
E	70,000	1.9	0.48	530	2,100

* Frame rate times the number of samples per frame. This assumes no lost time between samples. Multiply this value by the duty cycle for the actual values.

FIGURE 6.26 COMMUTATION SPECIFICATIONS FOR AUTOMATIC DECOMMUTATION

No. of Samples per Frame*	Frame Rate† (frames per second)	Commutation Rate‡ (samples per second)	Lowest Recommended Subcarrier Bands (cps)
18	5	90	14,500
18	10	180	22,000 (±15%) or 30,000 (± 7.5%)
18	25	450	30,000 (±15%) or 70,000 (± 7.5%)
30	2.5	75	10,500
30	5	150	22,000 (± 7.5%)
30	10	300	22,000 (±15%) or 40,000 (± 7.5%)
30	20	600	40,000 (±15%)
30	30	900	70,000 (±15%)

* The number of samples per frame available to carry information is three less than the number indicated because the equivalent of three samples is used in generating the frame synchronizing pulse.

† Commutator speed tolerance +5%; - 15%.

‡ Frame rate times number of samples per frame.

FIGURE 6.27 PDM/FM MISSILE TELEMETERING SYSTEM CHARACTERISTICS

PDM Telemetering is used for applications in which time division multiplexing will satisfy most of the data gathering requirements. A large number of channels with a low frequency response can be handled.

The RF transmitter may be frequency modulated (FM) or phase modulated (PM).

Detail characteristics are as follows:

Number of samples per frame*:	30	45	60	90
Frame rate (Frames/sec): (Commutator Speed)†	30	20	15	10
Commutation rate‡ (Samples/sec):	900	900	900	900
Minimum pulse duration (zero level information):	90 ± 30 microsec			
Maximum pulse duration (maximum level information):	660 ± 50 microsec			
Pulse rise time (measured between 10% and 90% levels):	20 microsec or less			

* The number of samples per frame available to carry information is two less than the number indicated because the equivalent of two samples is used in generating the frame synchronizing pulse.

†Commutator speed tolerance +5%; -15% from nominal.

‡Frame rate times number of samples per frame.

FIGURE 6.28 SUMMARY OF MILITARY NOMENCLATURE SYSTEM*

In the AN system for communication-electronic equipment, nomenclature consists of a name followed by a type number. The type number consists of indicator letters shown in the following tables and an assigned number.

The type number of an independent major unit, not part of or used with a specific set, consists of a component indicator, a number, the slant, and such of the set or equipment indicator letters as apply. Examples: SB-5/PT would be the type number of a portable telephone switchboard for independent use.

The system indicator (AN) does not mean that the Army, Navy, and Air Force use the equipment, but simply that the type number was assigned in the AN system.

* Adapted from "Summary of Joint Nomenclature System ("AN") System for Communication Electronic Equipment," Communications-Electronics Nomenclature Subpanel of the Joint Communications-Electronics Committee; Washington 25, D. C.: January 30, 1955.

FIGURE 6.28 SUMMARY OF MILITARY NOMENCLATURE SYSTEM (cont.)

NOMENCLATURE POLICY

AN nomenclature is assigned to:

a. Complete sets of equipment and major components of military design.

b. Groups of articles of either commercial or military design that are grouped for a military purpose.

c. Major articles of military design that are not part of or used with a set.

d. Commercial articles when nomenclature will facilitate military identification and/or procedures.

AN nomenclature will not be assigned to:

a. Articles cataloged commercially except in accordance with paragraph (d) above.

b. Minor components of military design for which other adequate means of identification are available.

c. Small parts such as capacitors and resistors.

d. Articles having other adequate identification in joint military specifications.

Nomenclature assignments will remain unchanged regardless of later changes in installation and/or application.

MODIFICATION LETTERS

Component modification suffix letters will be assigned for each modification of a component when detail, parts and subassemblies used therein are no longer interchangeable, but the component itself is interchangeable physically, electrically, and mechanically.

Set modification letters will be assigned for each modification not affecting interchangeability of the sets or equipment as a whole, except that in some special cases they will be assigned to indicate functional interchangeability and not necessarily complete electrical and mechanical interchangeability. Modification letters will only be assigned if the frequency coverage of the unmodified equipment is maintained.

The suffix letters X, Y, and Z will be used only to designate a set or equipment modified by changing the power input voltage, phase or frequency. X will indicate the first change, Y the second, Z the third, XX the fourth, etc., and these letters will be in addition to other modification letters applicable.

FIGURE 6.28 SUMMARY OF MILITARY NOMENCLATURE SYSTEM (cont.)

SET OR EQUIPMENT INDICATOR LETTERS

Type of Installation	Type of Equipment	Purpose
A Airborne (installed and operated in aircraft)	A Invisible light, heat radiation	A Auxiliary assemblies (not complete operating sets used with or part of two or more sets or sets series)
B Underwater mobile, submarine	B Pigeon	B Bombing
C Air transportable (inactivated, do not use)	C Carrier	C Communications (receiving and transmitting)
D Pilotless carrier	D Radiac	D Direction finder and/or reconnaissance
	E Nupac	E Ejection and/or release
F Fixed	F Photographic	
G Ground, general ground use (includes two or more ground type installations	G Telegraph or teletype	G Fire control or searchlight directing
		H Recording and/or reproducing (graphic meteorological and sound)
	I Interphone and public address	
	J Electro-mechanical (not otherwise covered)	
K Amphibious	K Telemetering	
	L Countermeasures	L Searchlight control (inactivated, use "G")
M Ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment)	M Meteorological	M Maintenance and test assemblies (including tools)
	N Sound in air	N Navigational aids (including altimeters, beacons, compasses, racons, depth sounding approach, and landing)

FIGURE 6.28 SUMMARY OF MILITARY NOMENCLATURE SYSTEM (cont.)

Type of Installation		Type of Equipment		Purpose	
P	Pack or portable (animal or man)	P	Radar	P	Reproducing (inactivated, do not use)
		Q	Sonar and underwater sound	Q	Special, or combination of purposes
		R	Radio	R	Receiving, passive detecting
S	Water surface craft	S	Special types, magnetic, etc., or combination of types	S	Detecting and/or range and bearing
T	Ground, transportable	T	Telephone (wire)	T	Transmitting
U	General utility (includes two or more general installation classes, airborne, shipboard, and ground)				
V	Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, etc., such as tanks)	V	Visual and visible light		
W	Water surface and underwater	W	Armament (peculiar to armament, not otherwise covered)	W	Control
		X	Facsimile or television	X	Identification and recognition

TABLE OF COMPONENT INDICATORS

AB	Supports, Antenna	CA	Commutator Assemblies, Sonar
AM	Amplifiers	CB	Capacitor Bank
AS	Antennas, Complex	CG	Cable Assemblies, rf
AT	Antennas, Simple	CK	Crystal Kits
BA	Battery, primary type	CM	Comparators
BB	Battery, secondary type	CN	Compensators
BZ	Signal Devices, Audible	CP	Computers
C	Controls	CR	Crystals

FIGURE 6.28 SUMMARY OF MILITARY NOMENCLATURE SYSTEM (cont.)

CU	Couplers	PU	Power Equipments
CV	Converters (electronic)	R	Receivers
CW	Covers	RC	Reels
CX	Cable Assemblies, non-rf	RD	Recorder-Reproducers
CY	Cases and Cabinets	RE	Relay Assemblies
D	Dispensers	RF	Radio Frequency Component
DA	Load, Dummy	RG	Cables, rf, Bulk
DT	Detecting Heads	RL	Reeling Machines
DY	Dynamotors	RO	Recorders
E	Hoists	RP	Reproducers
F	Filters	RR	Reflectors
FN	Furniture	RT	Receiver and Transmitter
FR	Frequency Measuring Devices	S	Shelters
G	Generators, Power	SA	Switching Devices
GO	Goniometers	SB	Switchboards
GP	Ground Rods	SG	Generators, Signal
H	Head, Hand, and Chest Sets	SM	Simulators
HC	Crystal Holder	SN	Synchronizers
HD	Air Conditioning Apparatus	ST	Straps
ID	Indicating Devices, non-crt	T	Transmitters
IL	Insulators	TA	Telephone Apparatus
IM	Intensity Measuring Devices	TB	Towed Body
IP	Indicators, Cathode-Ray Tube	TC	Towed Cable
J	Junction Devices	TD	Timing Devices
KY	Keying Devices	TF	Transformers
LC	Tools, Line Construction	TG	Positioning Devices
LS	Loudspeakers	TH	Telegraph Apparatus
M	Microphones	TK	Tool Kits
MA	Magazines	TL	Tools
MD	Modulators	TN	Tuning Units
ME	Meters	TR	Transducers
MF	Magnets or Mag-field Gens	TS	Test Items
MK	Miscellaneous Kits	TT	Teletypewriter and Facsimile App
ML	Meteorological Devices		
MT	Mountings	TV	Tester, Tube
MX	Miscellaneous	TW	Tapes, Recording Wires
O	Oscillators	U	Connectors, Audio & Power
OA	Operating Assemblies	UG	Connectors, rf
OC	Oceanographic Devices	V	Vehicles
OS	Oscilloscope, Test	VS	Signaling Equipment, Visual
PD	Prime Drivers	WD	Cables, Two-Conductor
PF	Fittings, Pole	WF	Cables, Four-Conductor
PG	Pigeon Articles	WM	Cables, Multiple-Conductor
PH	Photographic Articles	WS	Cables, Single-Conductor
PP	Power Supplies	WT	Cables, Three-Conductor
PT	Plotting Equipments	ZM	Impedance Measuring Devices

FIGURE 6.28 SUMMARY OF MILITARY NOMENCLATURE SYSTEM (cont.)

ADDITIONAL INDICATORS

Experimental sets: In order to identify a set or equipment of an experimental nature with the development organization concerned, the following indicators will be used within the parentheses:

XA	Communications-Navigation Laboratory, Wright Air Development Center, Dayton, Ohio.
XB	Naval Research Laboratory, Washington, D. C.
XC	Coles Signal Laboratory, Fort Monmouth, N. J.
XD	Cambridge Research Center, Cambridge, Mass.
XE	Evans Signal Laboratory, Fort Monmouth, N. J.
XF	Frankford Arsenal, Philadelphia, Pa.
XG	U. S. Navy Electronic Laboratory, San Diego, Calif.
XH	Aerial Reconnaissance Laboratory, Wright Air Development Center, Dayton, Ohio.
XJ	Naval Air Development Center, Johnsville, Pa.
XK	Flight Control Laboratory, Wright Air Development Center, Dayton, Ohio.
XL	Signal Corps Electronics Research Unit, Mountain View, Calif.
XM	Squier Signal Laboratory, Fort Monmouth, N. J.
XN	Department of the Navy, Washington, D. C.
XO	Redstone Arsenal, Huntsville, Ala.
XP	Canadian Department of National Defense, Ottawa, Canada.
XR	Engineer Research and Development Laboratory, Fort Belvoir, Va.
XS	Electronic Components Laboratory, Wright Air Development Center, Dayton, Ohio.
XU	U. S. Navy Underwater Sound Laboratory, Fort Trumbull, New London, Conn.
XW	Rome Air Development Center, Rome, N. Y.
XY	Armament Laboratory, Wright Air Development Center, Dayton, Ohio.

Example: Radio Set AN/ARC-3 ( ) might be assigned for a new airborne radio communication set under development. The cognizant development organization might then assign AN/ARC-3 (XA-1), AN/ARC-3 (XA-2), etc., type numbers to the various sets developed for test. When the set was considered satisfactory for use, the experimental indicator would be dropped and procurement nomenclature AN/ARC-3 would be officially assigned thereto.

FIGURE 6.28 SUMMARY OF MILITARY NOMENCLATURE SYSTEM (cont.)

Training sets: A set or equipment designed for training purposes will be assigned type numbers as follows:

a. A set to train for a specific basic set will be assigned the basic set type number followed by a dash, the letter T, and a number. Example: Radio Training Set AN/ARC-6A-T1 would be the first training set for Radio Set AN/ARC-6A.

b. A set to train for general types of sets will be assigned the usual set indicator letters followed by a dash, the letter T, and a number. Example: Radio Training Set AN/ARC-T1 would be the first training set for general airborne radio communication sets.

Parentheses indicator: A nomenclature assignment with parentheses, ( ) following the basic type number is made to identify an article generally, when a need exists for a more general identification than that provided by nomenclature assigned to specific designs of the article. Examples: AN/GRC-5 ( ), AM-6 ( )/GRC-5, SB-9 ( )/GG. A specific design is identified by the plain basic type number, the basic type number with a suffix letter, or the basic type number with an experimental symbol in parentheses. Examples: AN/GRC-5, AN/GRC-5A, AN/GRC-5 (XC-1), AM-6B/GRC-5, SB-9 (XE-3)/GG. The letter V within the parentheses is used to identify systems with varying parts list.

EXAMPLES OF AN TYPE NUMBERS

AN/SRC-3 ( )	General reference set nomenclature for water surface craft radio communication set number 3.
AN/SRC-3	Original procurement set nomenclature applied against AN/SRC-3 ( ).
AN/SRC-3A	Modification set nomenclature applied against AN/SRC-3.
AN/APQ-13-T1 ( )	General reference training set nomenclature for the AN/APQ-13 set.
AN/APQ-13-T1	Original procurement training set nomenclature applied against AN/APQ-13-T1 ( ).
AN/APQ-13-T1A	Modification training set nomenclature applied against AN/APQ-13-T1.
AN/UPT-T3 ( )	General reference training set nomenclature for general utility radar transmitting training set number 3.
AN/UPT-T3	Original procurement training set nomenclature applied against AN/UPT-T3 ( ).
AN/UPT-T3A	Modification training set nomenclature applied against AN/UPT-T3.
T-51 ( )/ARQ-8	General reference component nomenclature for transmitter number 51, part of or used with airborne radio special set number 8.
T-51/ARQ-8	Original procurement component nomenclature applied against T-51 ( )/ARQ-8.

FIGURE 6.28 SUMMARY OF MILITARY NOMENCLATURE SYSTEM (cont.)

EXAMPLES OF AN TYPE NUMBERS (cont.)

T-51A/ARQ-8	Modification component nomenclature applied against T-51/ARQ-8.
RD-31 ( )/U	General reference component nomenclature for recorder-reproducer number 31 for general utility use, not part of a specific set.
RD-31/U	Original procurement component nomenclature applied against RD-31 ( )/U.
RD-31A/U	Modification component nomenclature applied against RD-31/U.

FIGURE 6.29 SEMICONDUCTOR MATERIALS AND APPLICATIONS

Device	Semiconductor	Type	Applications
Transistors	Germanium	Junction	General-purpose to 70°C
	Germanium	Point-contact	Computors
	Silicon	Junction	High-temperature use
Rectifiers	Germanium	Point-contact diode	Economical, useful to vhf
	Germanium	Junction diode	High-rectification-ratio diode
	Germanium	Junction diode	Power rectifier
	Silicon	Point-contact diode	Microwave detector, mixer
	Silicon	Junction diode	Very-high-rectification-ratio diode, voltage control or reference
	Silicon	Junction diode	Power rectifier
	Selenium	Dry-disk	Power-supply rectifier, low-frequency diode
	Copper oxide	Dry-disk	Meter rectifier, ring modulator
	Copper sulfide	Dry-disk	Low-voltage power rectifier

FIGURE 6.29 SEMICONDUCTOR MATERIALS AND APPLICATIONS (cont.)

Device	Semiconductor	Type	Applications
Varistors	Silicon carbide	Fired	Voltage surge suppressor, voltage limiter
	Selenium	Dry-disk	Contact protector
	Copper oxide	Dry-disk	Voltage surge suppressor
Thermistors	Mixed metallic oxides	Fired	Temperature sensing, current surge suppressor, temperature compensation
Photoconductive cells	Germanium	Junction	General-purpose
	Germanium	Point-contact	Phototransistor
	Lead sulfide	–	Infrared detector
	Lead telluride	–	Infrared detector
Photoelectric cells	Silicon	Junction	Power source for transistors
	Cadmium sulfide	Junction	Power source for transistors
	Selenium	Dry-disk	Light meter

FIGURE 6.30 STANDARD WAVEGUIDES

Radio-Electronics Television Manufacturers Association designation	Army-Navy type number *	outer dimensions and wall thickness	frequency range in kilomegacycles for dominant ($TE_{1,0}$) mode	cutoff wave-length λ_c in centimeters for $TE_{1,0}$ mode	cutoff frequency f_c in kilomega-cycles for $TE_{1,0}$ mode	theoretical attenuation, lowest to highest frequency in db/100 ft	theoretical power rating in mega-watts for lowest to highest frequency ‡
WR1500		15.000 × 7.500 †	0.47 – 0.75	76.3	0.393		
WR1150		11.500 × 5.750 †	0.64 – 0.96	58.4	0.514		
WR975		10.000 × 5.125 × 0.125	0.75 – 1.12	49.6	0.605		
WR770		7.950 × 4.100 × 0.125	0.96 – 1.45	39.1	0.767		
WR650	RG-69/U	6.660 × 3.410 × 0.080	1.12 – 1.70	33.0	0.908	0.317– 0.212	11.9 –17.2
WR510		5.260 × 2.710 × 0.080	1.45 – 2.20	25.9	1.16		
WR430	RG-104/U	4.460 × 2.310 × 0.080	1.70 – 2.60	21.8	1.375	0.588– 0.385	5.2 – 7.5
WR340		3.560 × 1.860 × 0.080	2.20 – 3.30	17.3	1.735		
WR284	RG-48/U	3.000 × 1.500 × 0.080	2.60 – 3.95	14.2	2.08	1.102– 0.752	2.2 – 3.2
WR229		2.418 × 1.273 × 0.064	3.30 – 4.90	11.6	2.59		
WR187	RG-49/U	2.000 × 1.000 × 0.064	3.95 – 5.85	9.50	3.16	2.08 – 1.44	1.4 – 2.0
WR159		1.718 × 0.923 × 0.064	4.90 – 7.05	8.09	3.71		
WR137	RG-50/U	1.500 × 0.750 × 0.064	5.85 – 8.20	6.98	4.29	2.87 – 2.30	0.56 – 0.71
WR112	RG-51/U	1.250 × 0.625 × 0.064	7.05 – 10.00	5.70	5.26	4.12 – 3.21	0.35 – 0.46
WR90	RG-52/U	1.000 × 0.500 × 0.050	8.20 – 12.40	4.57	6.56	6.45 – 4.48	0.20 – 0.29
WR75		0.850 × 0.475 × 0.050	10.00 – 15.00	3.81	7.88		
WR62	RG-91/U	0.702 × 0.391 × 0.040	12.4 – 18.00	3.16	9.49	9.51 – 8.31	0.12 – 0.16
WR51		0.590 × 0.335 × 0.040	15.00 – 22.00	2.59	11.6		
WR42	RG-53/U	0.500 × 0.250 × 0.040	18.00 – 26.50	2.13	14.1	20.7 –14.8	0.043 – 0.058
WR34		0.420 × 0.250 × 0.040	22.00 – 33.00	1.73	17.3		
WR28	RG-96/U (*)	0.360 × 0.220 × 0.040	26.50 – 40.00	1.42	21.1	21.9 –15.0	0.022 – 0.031
WR22	RG-97/U (*)	0.304 × 0.192 × 0.040	33.00 – 50.00	1.14	26.35	31.0 –20.9	0.014 – 0.020
WR19		0.268 × 0.174 × 0.040	40.00 – 60.00	0.955	31.4		
WR15	RG-98/U (*)	0.228 × 0.154 × 0.040	50.00 – 75.00	0.753	39.9	52.9 –39.1	0.0063– 0.0090
WR12	RG-99/U (*)	0.202 × 0.141 × 0.040	60.00 – 90.00	0.620	48.4	93.3 –52.2	0.0042– 0.0060
WR10		0.180 × 0.130 × 0.040	75.00 –110.00	0.509	59.0		

* In this column, types marked with asterisk are silver; unmarked types are brass.

† Inner dimensions only are specified.

‡ For these computations, the breakdown strength of air was taken as 15,000 volts per centimeter. A safety factor of approximately 2 at sea level has been allowed.

FIGURE 6.31 GRAPHICAL SYMBOLS

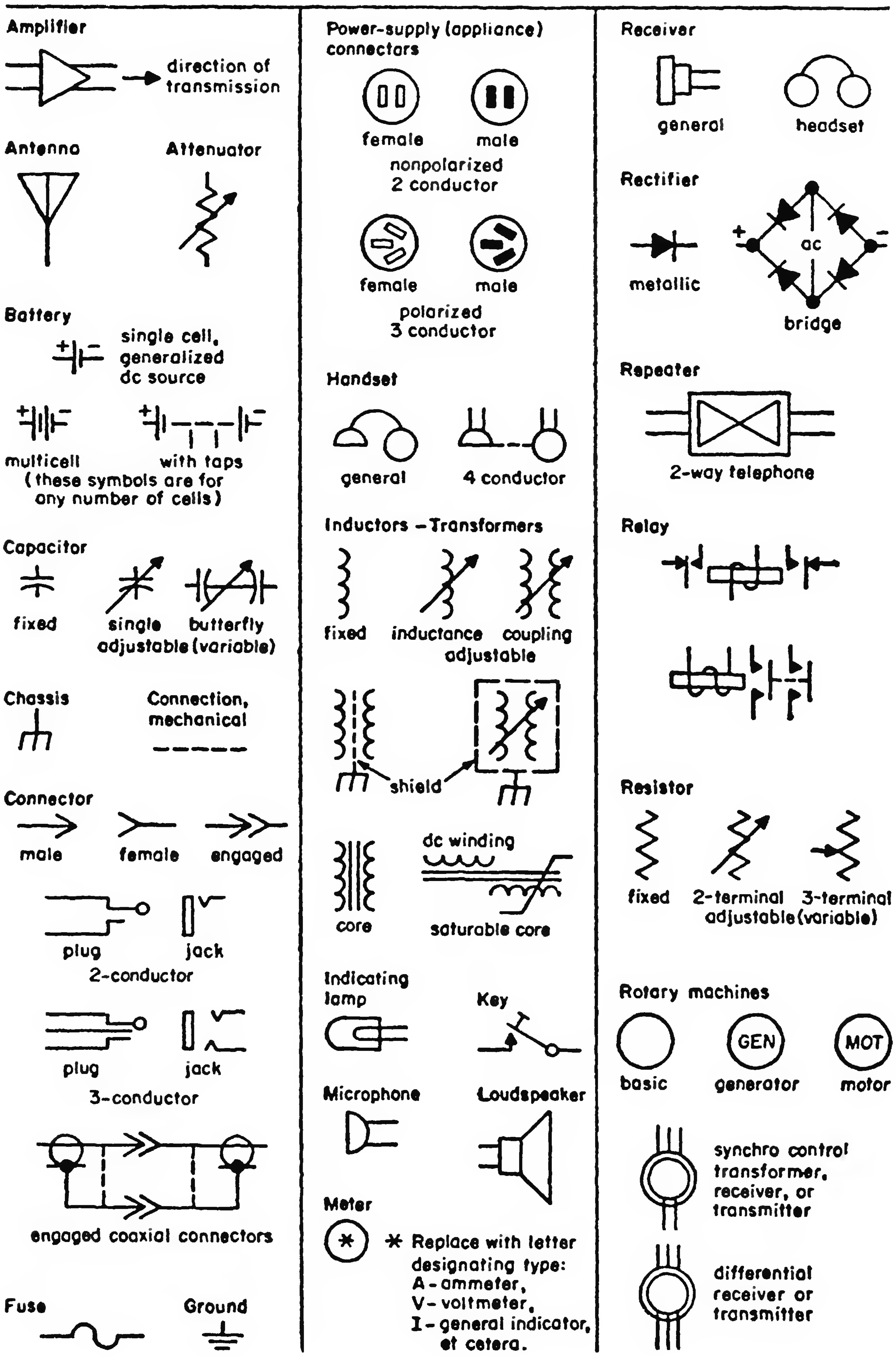
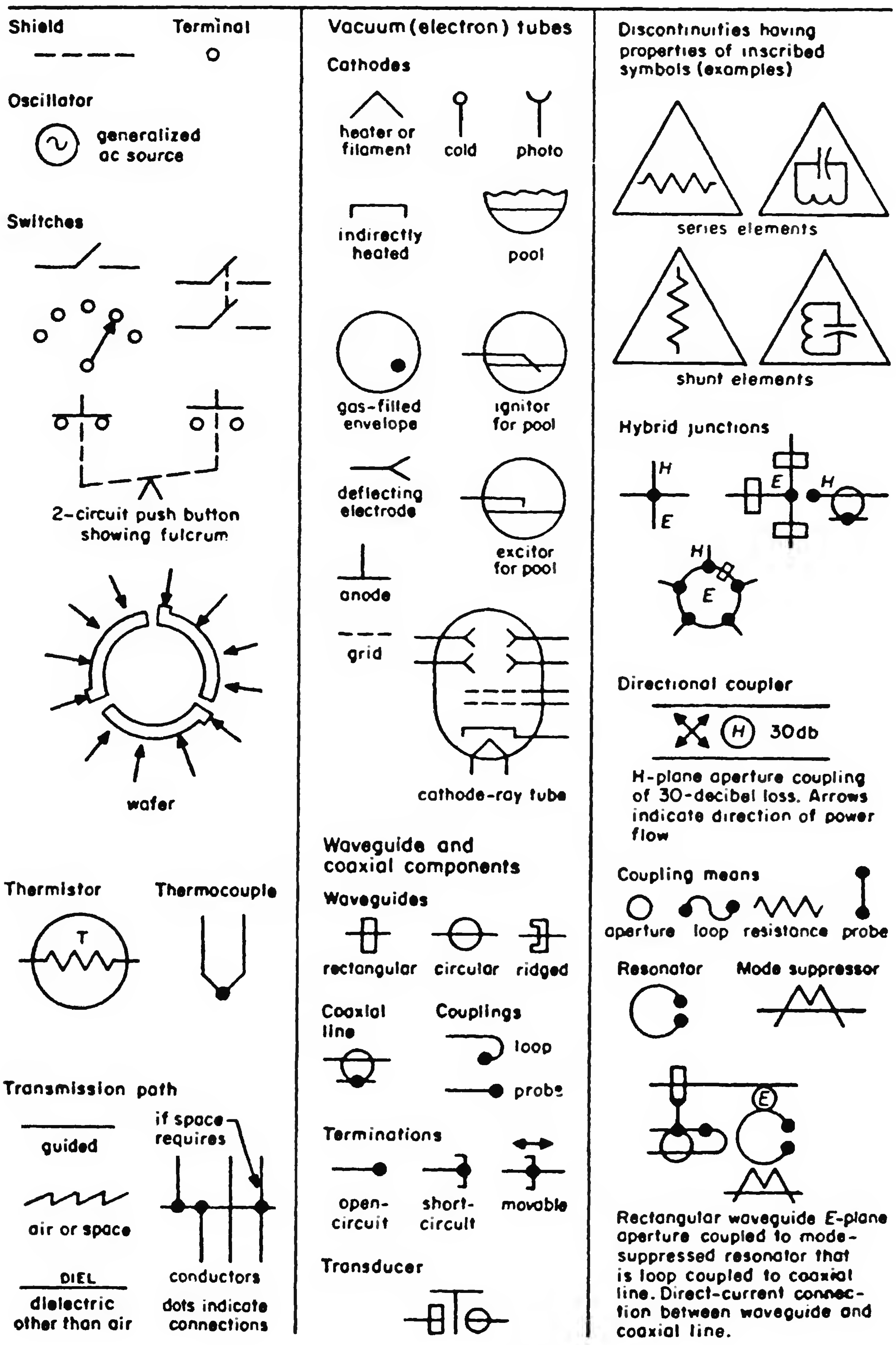


FIGURE 6.31 GRAPHICAL SYMBOLS (cont.)



SECTION 7—PROPULSION

PRINCIPAL NOTATIONS

a	=	Speed of sound, fps
a_2	=	Experimental constant
A	=	Initial acceleration, fps^2
A_e	=	Exhaust jet area, sq in.
A_p	=	Burning surface, sq in.
A_t	=	Nozzle throat area, sq in.
c^*	=	Characteristic velocity, fps
c_w	=	Weight flow coefficient
C_f	=	Thrust coefficient
d_p	=	Density of propellant, gm/cc
D	=	Drag, lb
f	=	$\frac{w_f}{w_a}$ = Fuel air ratio
F	=	Thrust, lb
g	=	Acceleration of gravity, fps^2
g_e	=	Gravity at earth surface, fps^2
g_h	=	Gravity at h altitude, fps^2
h	=	Altitude, ft
I	=	Total impulse (lb. sec. = $F\Delta t$ = $W_p I_{sp}$)
I_D	=	Density impulse, lb sec/cu in.
I_o	=	Over-all impulse, lb sec/lb
I_{sp}	=	Specific impulse, lb sec/lb
k	=	Ratio of specific heats, c_p/c_v
k	=	Temperature constant
K_n	=	Area ratio
$\dot{m}$	=	Mass flow rate = $\frac{\dot{w}}{g}$, slugs/sec
m_o	=	Mass of loaded vehicle
m_p	=	Mass of propellants
M_o	=	Molecular weight of gases
n	=	Exponent of burning rate, usually between 0.4 and 0.8

PRINCIPAL NOTATIONS (cont.)

N	=	$\dfrac{W_o}{W_e} = \dfrac{\text{loaded weight}}{\text{empty weight}}$
η_p	=	Propulsion efficiency
p_a	=	Ambient pressure, psi
p_c	=	Chamber pressure, psi
P	=	Atmospheric pressure, psia
P	=	Power, ft lb/sec
P_e	=	Exit pressure, psi
r	=	Mixture ratio of oxidizer to fuel
r_o	=	Linear burning rate, in./sec
R	=	Gas constant, 1545 ft/°R
R_e	=	Radius of earth, ft.
$R_{I/W}$	=	Impulse weight ratio
SFC	=	Specific fuel consumption
t	=	Time, sec
t_c	=	Stay time of gases in combustion chamber
T	=	Temperature, deg F
T_c	=	Temperature of combustion, absolute
v	=	Absolute vehicle velocity, fps
ν	=	$\dfrac{V}{\omega}$ = speed ratio
ν_1	=	Average specific volume of propellant gases in the chamber, cu in./lb
V_c	=	Chamber volume, cu in.
V_j	=	Exhaust jet velocity, fps
$\dot{w}$	=	Weight flow or rate of propellant, lb/sec
w_o	=	Weight of oxidizer
w_f	=	Weight of fuel
W_o	=	Over-all weight, lb
w_p	=	Propellant weight, lb
ω	=	Lateral velocity of fluid, fps
γ_p	=	Specific weight of propellant, lb/cu in.
γ'_p	=	$\gamma_p - \gamma_g$ = Difference in specific weight of the propellant and the gases in the free volume of the combustion chamber, lb/cu in.
$\int p\,dt$	=	Pressure-time integral, psi-sec
ϕ_p	=	Pressure sensitivity to temperature, per cent/deg F

SECTION 7.1 GENERAL PROPULSION DATA

GENERAL JET PROPULSION EQUATIONS

Propulsive force exerted by a jet propulsion engine

Eq. 7.1.1 Thrust

$$F = \frac{\dot{w} V_j}{g} + A_e(P_e - P)$$

In a perfect vacuum $P = 0$ indicating an increase in thrust as a function of altitude

Eq. 7.1.2 Thermal jet engine thrust (air burning engine)

$$F = \left(\frac{1 + f}{\nu} - 1\right) \frac{\dot{w}_a}{g} + (P_e - P_o)A_e$$

Eq. 7.1.3 Rocket engine thrust

$$F = \frac{\dot{w}}{g} \omega + (P_e - P_o)A_e = \frac{\dot{w}}{g} V_j$$

Eq. 7.1.4 Thrust power

$$P_T = FV = DV$$

Eq. 7.1.5 Propulsive power

$$P = \frac{\dot{m} c^2}{2} + FV$$

$$c = V_j - V \qquad \text{for jet engines}$$

Eq. 7.1.6 Propulsive efficiency-Ideal

$$\eta_p = \frac{\text{useful work done per unit time}}{\text{work supplied for propulsion}} = \frac{P_T}{P}$$

$$\eta_p = \frac{P_T}{P_T + P_L}$$

where $\eta_p > \eta_p$

for thermal jet propulsion

$$\eta_p = \frac{2\nu}{1 + \nu}$$

for rocket propulsion

$$\eta_p = \frac{2\nu}{1 + \nu^2}$$

Eq. 7.1.7 Mach number (for a perfect gas)

$$M = \frac{V}{a} = \frac{V}{\sqrt{gkRt}}$$

GENERAL JET PROPULSION EQUATIONS (cont.)

a = local velocity of sound

t = local temperature, °F

a(MPH) = $33.44\ T^{1/2}$ (°Fabs = t + 460)

a(MPH) = $44.86\ T^{1/2}$ (°Cabs = t + 273)

a(KNOTS) = $29.04\ T^{1/2}$ (°Fabs = t + 460)

a(KNOTS) = $38.96\ T^{1/2}$ (°Cabs = t + 273)

Eq. 7.1.8 Reference speeds

In jet propulsion thermodynamics, the speeds c, a_o, and a^* are reference speeds which remain constant for a given set of stagnation conditions. Reference speeds are related to each other; thus for gases with k = 1.4:

$$\frac{c}{a^*} = \sqrt{\frac{k+1}{k-1}} = 2.45 \qquad \frac{c}{a_o} = \sqrt{\frac{2}{k-1}} = 2.24$$

$$\frac{a^*}{a_o} = \sqrt{\frac{2}{k+1}} = 0.913$$

FIGURE 7.1.1 NOZZLE DESIGN CHART

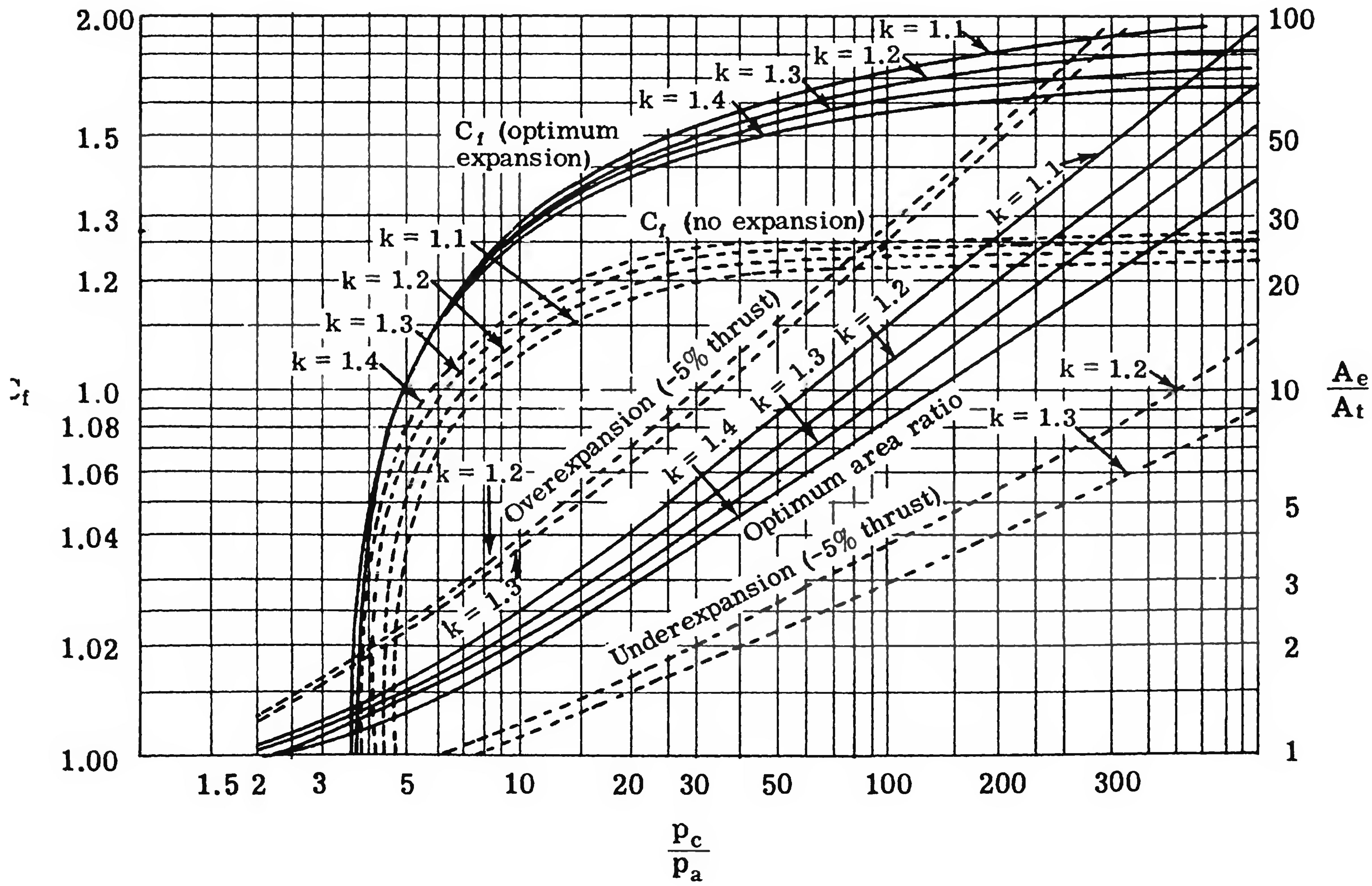


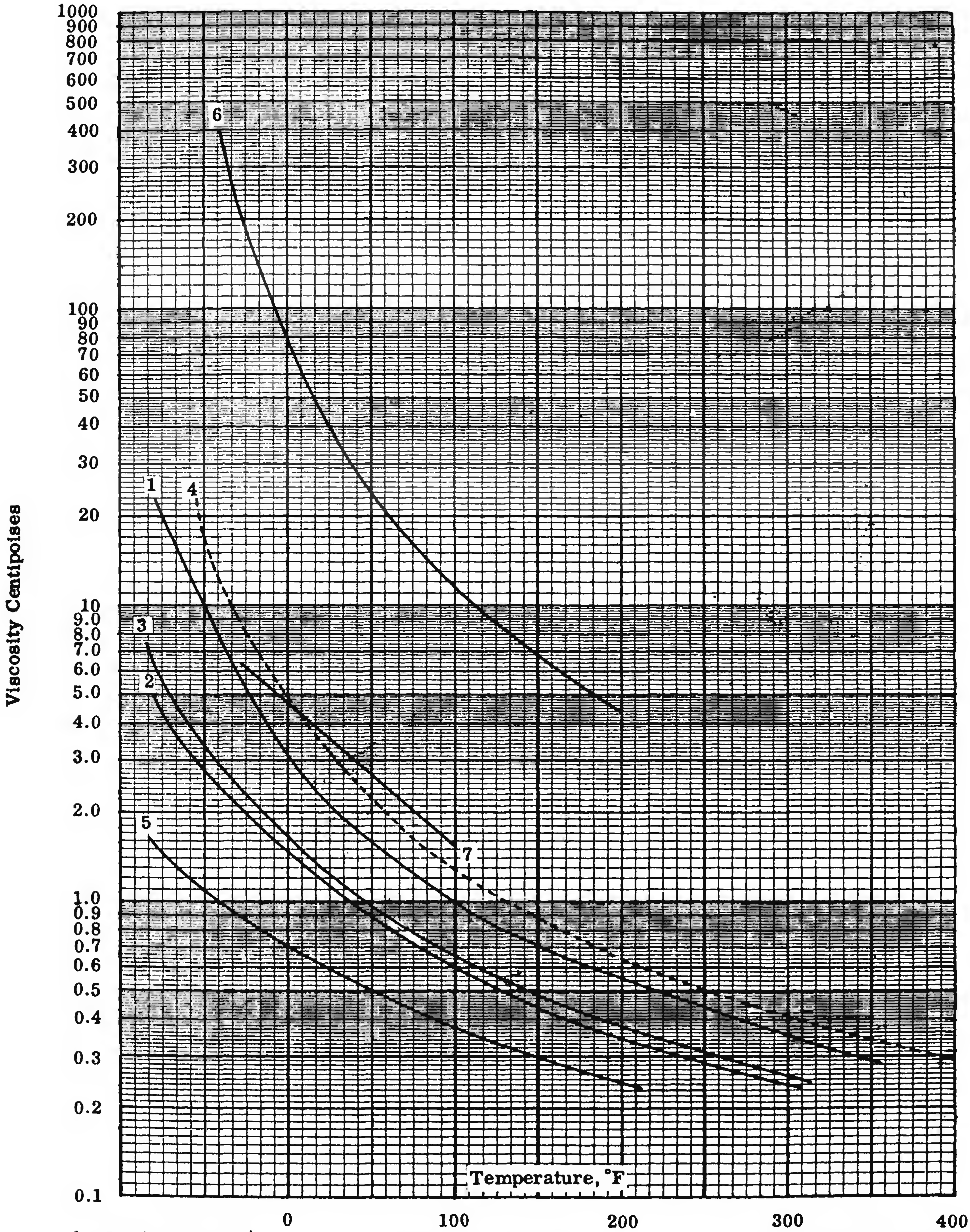
FIGURE 7.1.2 PROPERTIES OF SOME TYPICAL HYDROCARBON FUELS

	Jet Fuel	Jet Fuel	Kerosene	Aviation Gasoline 100/130	Diesel Fuel
Specific gravity at 60°F	0.78	0.76	0.81	0.73	0.85
Density at 60°F, lb/ft^3	48.7	47.5	50.6	45.6	53
Freezing point, °F	-76 (max)	-76 (max)	-45	-76	-10
Viscosity at 60°F Centipoise	1.4	1.3	1.6	0.5	2
Flash point, °F (TCC)	24	-17	137	-20	140
ASTM distillation, °F					
10% evaporated	165	163	—	147	440
50% evaporated	340	313	—	205	—
90% evaporated	460	435	—	245	650
Reid vapor pressure, psia	2 to 3	5 to 7	below 1	7	0.1
Specific heat, Btu/lb °F	0.50	0.51	0.49	0.53	0.47
Average moleculat weight, lb/mole	130	125	175	90	—
Heat content	—	18564	18492	18700	(80190,100)
Btu/cu ft	—	—	946,600	18900 790,000	(815-145)

FIGURE 7.1.3 FUEL COMPARISONS

	Specific Gravity	Heat of Combustion	
		Btu/lb	Btu/cu. ft.
Acetylene C_2H_2	0.621	20,735	803,550
Aluminum	2.70	13,310	2,245,000
Benzene C_6H_6	1.25	17,190	1,343,000
Beryllium	1.85	29,140	3,365,450
Boron	2.3	25,100	3,604,000
Carbon (graphite)	2.25	14,090	1,978,700
Carbon disulfide (CS_2)	—	5,960	—
Diborane	0.447	31,370	875,400
Ethanol C_2H_5OH	0.738	11,930	550,000
Ethylene C_2H_4	0.449	20,350	570,000
Hydrogen H_2	0.070	51,570	225,360
Hydrocarbon oils $C_nH_{2n} + 2$	—	22,000	—
Lithium	0.534	18,460	615,400
Lithium hydride	0.82	17,760	909,150
Magnesium	1.74	10,640	1,155,660
Methane CH_4	0.257	21,530	346,000
Methanol CH_3OH	0.514	9,080	291,000
Pentaborane	0.61	29,130	1,109,190
Propane C_3H_8	—	19,940	—
Silicon	2.4	13,170	1,973,230
Silane	0.68	17,160	728,460
Titanium	4.5	8,190	2,299,950
Gasoline C_8H_{18}	0.678	18,800 - 19,250	790,000
Kerosene	0.820	18,490	946,600

FIGURE 7.1.4 VISCOSITIES OF AIRCRAFT FLUIDS AT ONE ATMOSPHERE



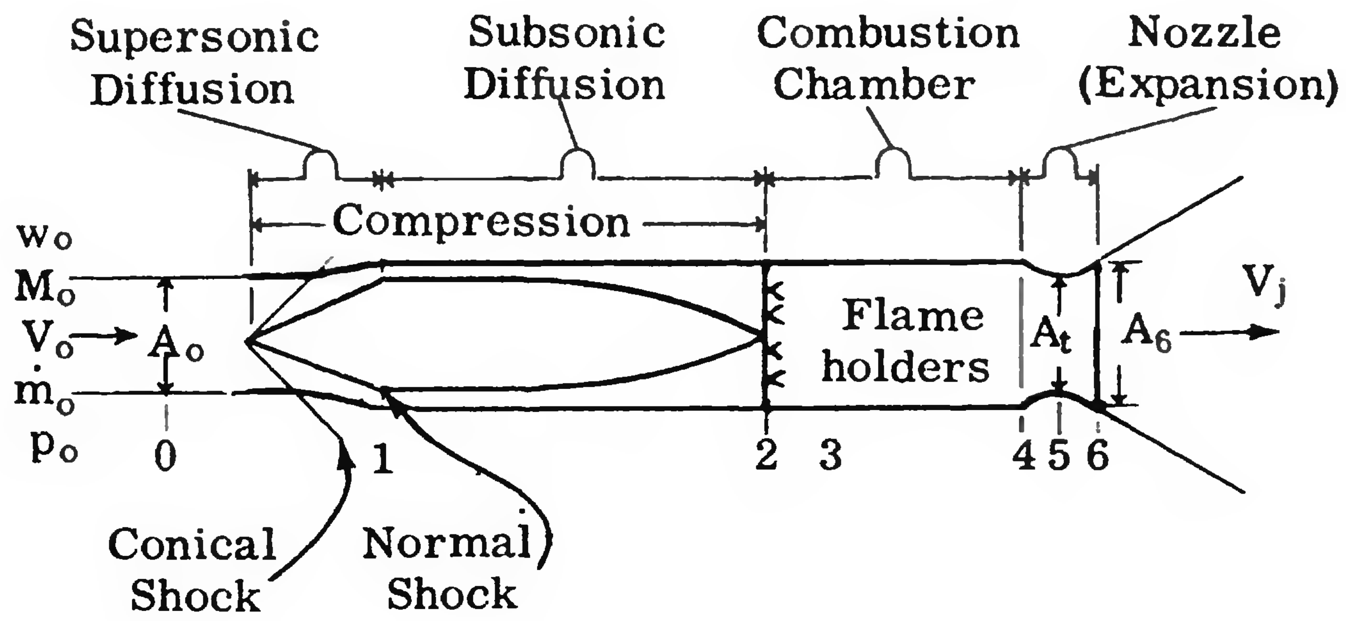
1 JP-1 Mil-F-5616
2 JP-3 MIL-F-5624A
3 JP-4 MIL-F-5624A
4 JP-5 MIL-F-7914 (AER)
5 Aviation Gasoline MIL-F-5572
6 MIL-O-5606
7 MIL-F-25576A (USAF)

For Conversion From Centipoises To:

lb./sec.-ft. Multiply by	0.000672	kg./hr.-m. Multiply by	3.60
lb./hr.-ft. Multiply by	2.42	gm./sec.-cm. = poises Divide by	100
Slugs/sec.-ft. = (lb. force) (sec.)/(sq. ft.) Multiply by	0.0000209		

SECTION 7.2 RAMJET ENGINES

RAMJET ENGINE EQUATIONS



Eq. 7.2.1 Stream thrust

$$\mathfrak{F} = \dot{m}V + pA$$

Eq. 7.2.2 Gross thrust

$$F_g = \mathfrak{F}_6 - \mathfrak{F}_o - p_o(A_6 - A_o)$$

$$= \dot{m}_6 V_6 - \dot{m}_o V_o + A_6(p_6 - p_o) = \frac{\dot{w}}{g} V_j$$

Eq. 7.2.3 Net thrust

$$F_n = F_g - D_e = \frac{\dot{w}_6}{g} V_j - \frac{\dot{w}_o}{g} V_o \simeq \frac{\dot{w}_o}{g} (V_j - V_o)$$

D_e = external drag

Eq. 7.2.4 Effective exhaust velocity

$$V_j = V_6 + \frac{A_6 g}{\dot{m}_6}(p_6 - p_o); \text{ if } p_6 = p_o \text{ then } V_j = V_6$$

Eq. 7.2.5 Effective jet mach number

$$M_j = \frac{V_j}{a_6}$$

a_6 = acoustic velocity

Eq. 7.2.6 Net thrust coefficient

$$C_{fn} = \frac{F_n}{q_o A_m} = \frac{F_g - D_e}{\frac{1}{2} \rho_o V_o{}^2 A_m}$$

$$= \frac{2(F_g - D_e)}{p_o A_m k_o M_o{}^2}$$

A_m = maximum area of engine

$k_o = \frac{C_p}{C_v}$ specific heat ratio for the free-stream air

Eq. 7.2.7 Overall efficiency

$$\eta_o = \frac{k_o(k_B - 1)M_o^2\left[(1 + f)\frac{M_j}{M_o}\left(\frac{\alpha k_B/k_o}{1 + \frac{k_6 - 1}{2}M_o^2}\right)^{\frac{1}{2}} - 1\right]}{k_B\left[\alpha - \left(1 + \frac{k_o - 1}{2}M_o^2\right)\right]}$$

k_B = specific heat ratio of gases

f = fuel/air ratio

α = nozzle exit half angle

Eq. 7.2.8 Specific fuel consumption (SFC)

$$SFC = \frac{\dot{w}_f}{F_n}$$

Eq. 7.2.9 Specific impulse

$$I_{sp} = \frac{3600}{SFC}$$

Eq. 7.2.10 Gross thrust specific fuel consumption

$$F_g SFC = \frac{3600\dot{w}_f}{F_g} = \frac{3600\dot{w}_f}{C_{fg}\left(\frac{1}{2}A_m p_o k_o M_o^2\right)}$$

Eq. 7.2.11 Flow through diffusers

Ram pressure ratio (ratio of total pressure leaving diffuser, P_2, to static pressure of free stream, p_o)

Normal shock diffuser (approx.)

$$\frac{P_2}{p_o} = \left(\frac{7 + \eta_d}{6}\right)M_o^2$$

η_d = diffuser efficiency

(1) for values of $M_o > 2.0$ the ram pressure ratio P_2/p_o is approximately proportional to M_o^2;

(2) for $\eta_d = 1.0$, the minimum ram effectiveness is 0.76 and occurs at $M_o = 5.0$ approximately

(3) for values of $\eta_d < 1.0$ the ram effectiveness is improved by normal shock compression at low values of M_o; and

(4) for any value of η_d, the ram effectiveness becomes asymptotic to 1.0 at very large values of M_o.

RAMJET ENGINE EQUATIONS (cont.)

Eq. 7.2.12 Diffuser efficiency

$$\eta_D = 1 - \frac{2}{(k-1)M_o^2}\left[\left(\frac{P}{p_2}\right)^{\frac{k-1}{k}} - 1\right] = 1 - \frac{2Z_D}{(k-1)M_o^2};\ Z_D = \left(\frac{P}{p_2}\right)^{\frac{k-1}{k}} - 1$$

if $k = 1.4$

$$\eta_D = 1 - \frac{5}{M_o^2}(Z_D)$$

Eq. 7.2.13 Ram effectiveness

$$\eta_r = \frac{p_2 - p_o}{P - p_o}$$

P = total pressure of free stream

RAMJET PERFORMANCE CALCULATIONS

Several methods may be used but the second given is preferred.

Method 1

The axial or zero-lift drag is defined as the integral of all axial components of forces acting on the outside of the body, with attached flow conditions at the lip of the inlet. Thrust is the corresponding integral of axial forces acting on the inside of the body.

Calculate drag with the burner on and with the burner off; the difference will be greater or less than that due to the exit area of the jet, depending on whether the design characteristics of the base and the jet are such as to cause an increase or decrease in base pressure under burning conditions.

Method 2

Nose wave drag is charged to thrust rather than drag because the nose shape is set by internal flow and engine requirements and because of the effect of internal flow conditions on external drag under certain operating conditions. The advantage is that the cowl drag does not have to be known or measured separately in tests aimed at obtaining the overall thrust and drag characteristics of the missile.

Method 3

Diffuser losses and nose wave drag are considered a part of the total drag based on definition that the engine is the only thrust-producing unit and should not be charged with drag or other losses occurring elsewhere in the missile.

FIGURE 7.2.1 IDEAL RAMJET PERFORMANCE M VS. SPECIFIC FUEL CONSUMPTION

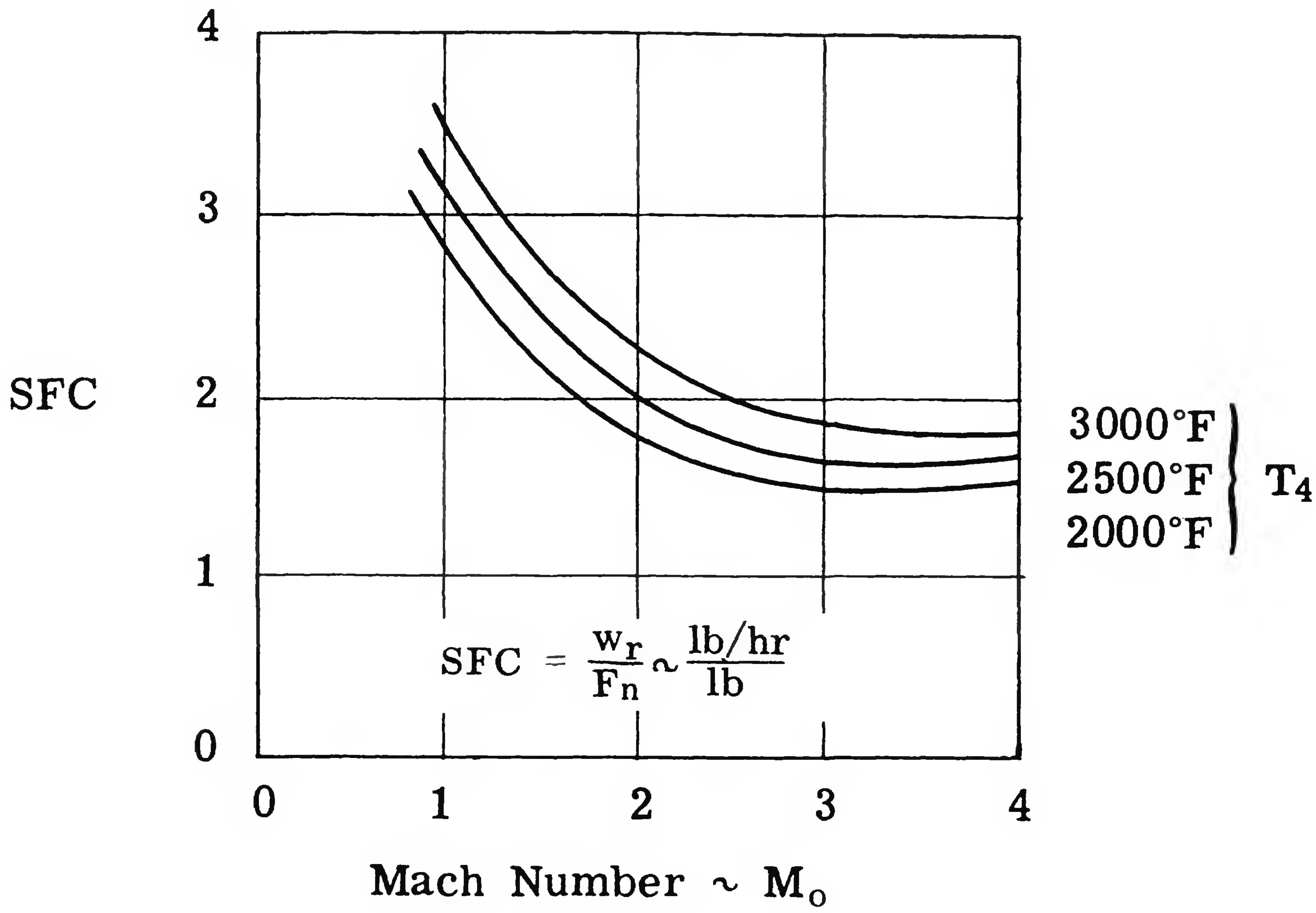


FIGURE 7.2.2 IDEAL RAMJET PERFORMANCE M VS NET THRUST

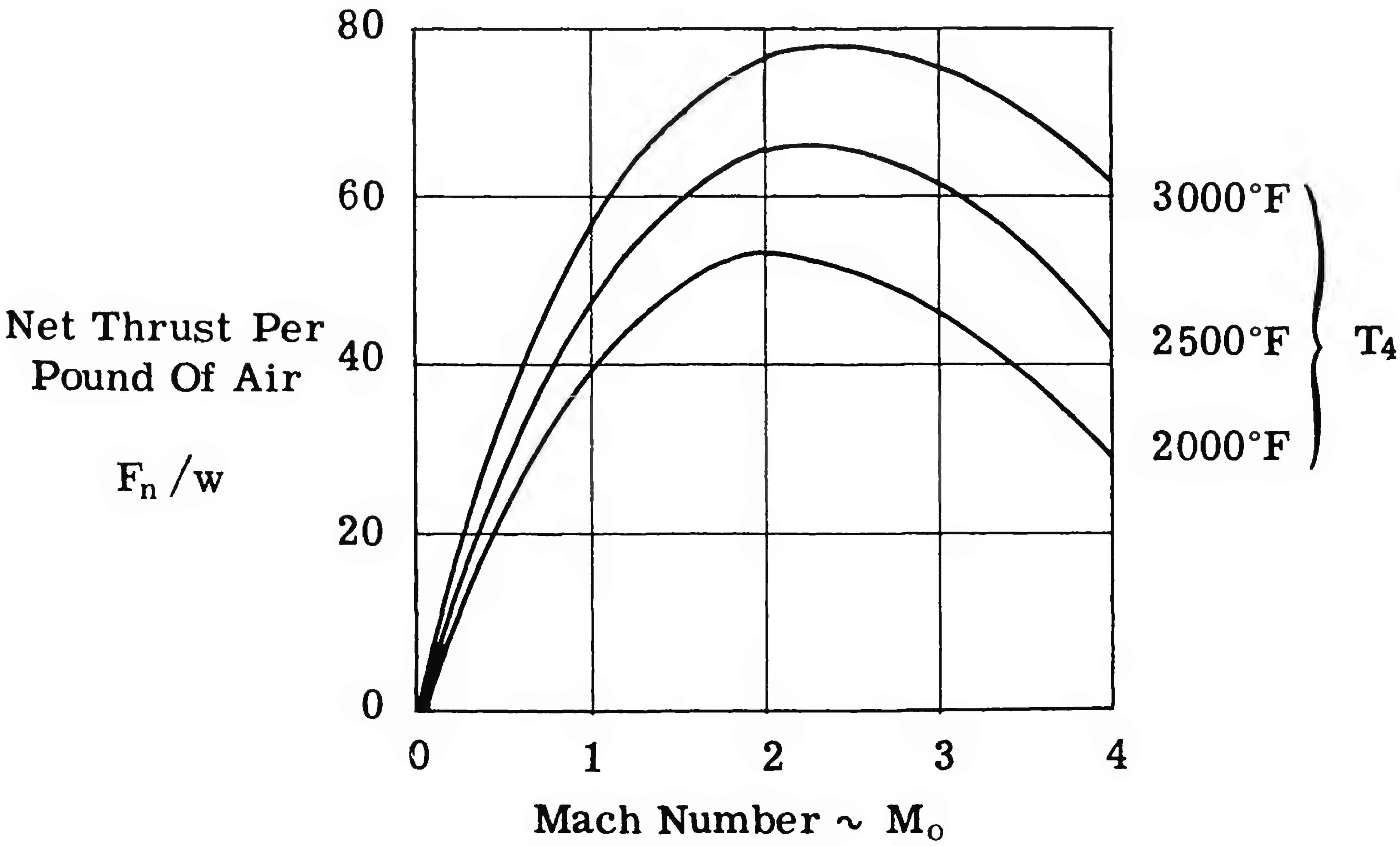


FIGURE 7.2.3(A) RATIOS P/P_0 and p/P_0 AS A FUNCTION OF THE FREE-STREAM MACH NUMBER FOR CONICAL SHOCK SUPERSONIC DIFFUSERS WITH DIFFERENT NUMBERS OF SHOCKS

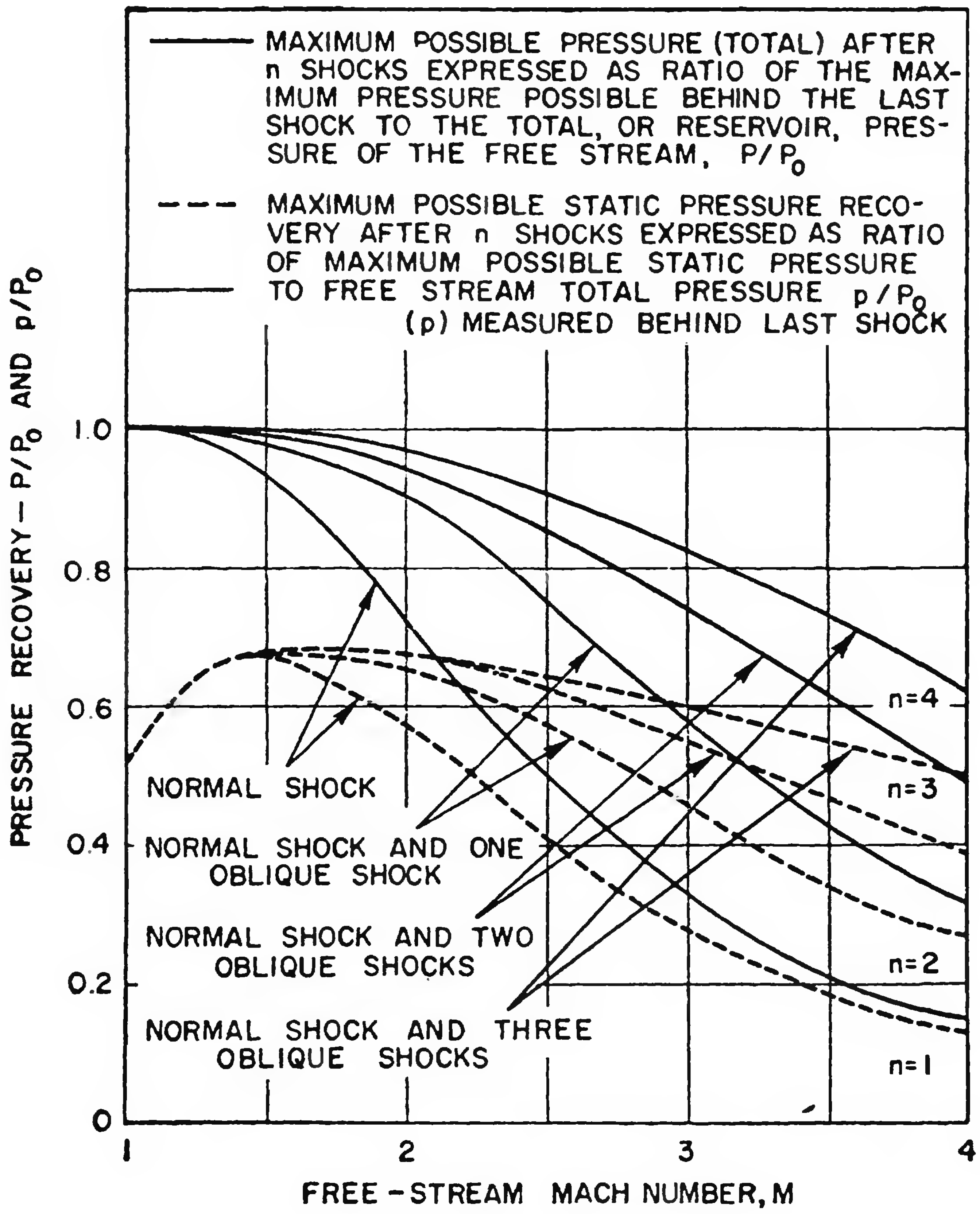
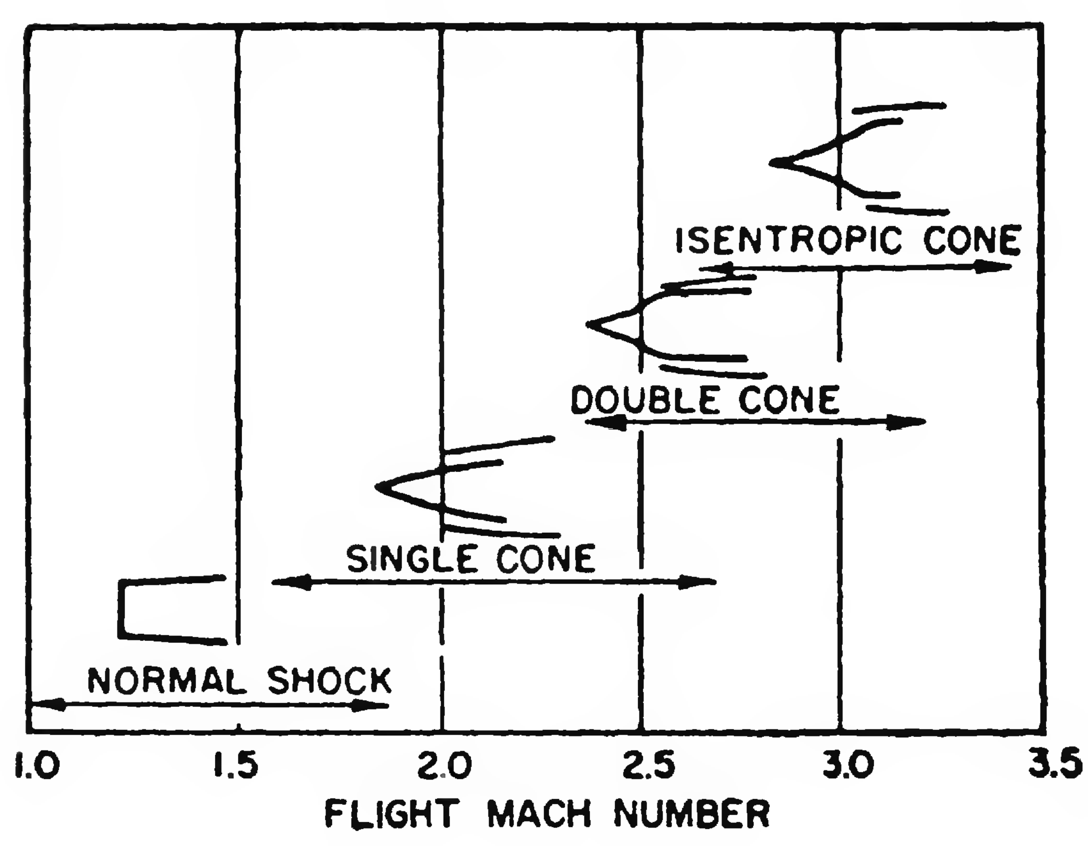
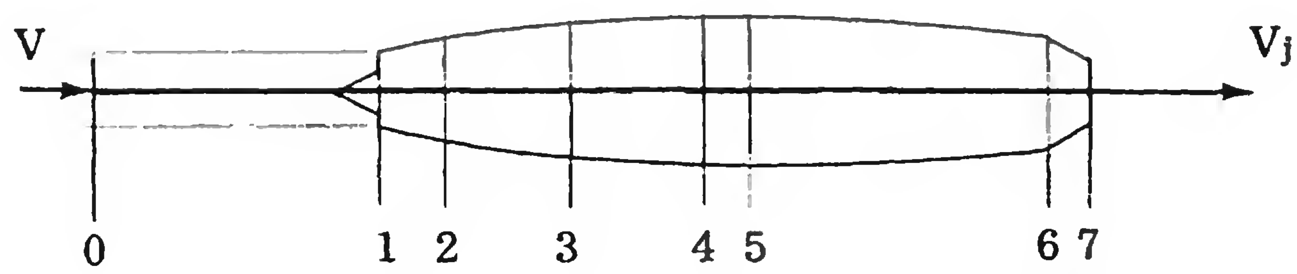


FIGURE 7.2.3(B) BEST DESIGN OPERATING RANGES FOR DIFFERENT SUPERSONIC DIFFUSERS FOR RAMJET ENGINES



SECTION 7.3 TURBOJET ENGINES

TURBOJET ENGINE EQUATIONS



Eq. 7.3.1 Thrust

$$F = \frac{\dot{w}}{g}(V_j - V)$$

Eq. 7.3.2 Specific Thrust (Air Specific Impulse)

$$I_{sp} = \frac{1}{g}(V_j - V) = \frac{V_j}{g}(1 - \nu) \quad \text{where } \nu = \frac{V}{V_j}$$

Eq. 7.3.3 Dimensionless Thrust Parameter

$$\lambda = \frac{gI_{sp}}{c_o} \text{ where } c_o = \sqrt{2gJc_pT_o} \quad J = \text{mechanical equivalent of heat}$$

Eq. 7.3.4 Jet Speed

$$V_j = \sqrt{2gJ\Delta h_n} \quad \text{where } \Delta h_n = \text{enthalpy change in the nozzle}$$

Eq. 7.3.5 Thrust Specific Fuel Consumption (TSFC)

$$TSFC = 3600 \frac{\dot{w}_f}{F} \text{ (lb fuel/hr per lb of thrust)}$$

Eq. 7.3.6 Overall efficiency

$$\eta_o = \frac{FV}{\dot{w}_f \Delta H_c} \quad \text{where } \Delta H_c = \text{calorific value of fuel, Btu/lb}$$

Eq. 7.3.7 Thrust Augmentation

$$V_j = \varphi \sqrt{2g \frac{k}{k-1} RT_6 \left[1 - \left(\frac{p_7}{p_6}\right)^{\frac{k-1}{k}}\right]} \quad \text{where}$$

$\varphi = \sqrt{\eta_n}$ and η_n=nozzle eff.
T_6 = temp. at exit, °R
T_{6a} = temp. at exit with afterburning, °R

Eq. 7.3.8 Augmented Velocity Ratio

$$\frac{V_{ja}}{V_j} = \sqrt{\frac{T_{6a}}{T_6}}$$

Eq. 7.3.9 Augmented Thrust Ratio

$$\frac{F_a}{F} = \frac{V_{ja} - V}{V_j - V} = \frac{\sqrt{\frac{T_{6a}}{T_6}} - \nu}{1 - \nu}$$

FIGURE 7.3.1 JET THRUST AT VARIOUS HORSEPOWERS AND TRUE AIRSPEEDS

$$\text{Thrust (lbs)} = \frac{\text{Power (ft lbs/sec)}}{\text{Velocity (ft/sec)}}$$

$$= \frac{550 \times HP}{1.688 \times \text{Knots}} = 325.867 \frac{HP}{\text{Knots}}$$

$$= 375 \times 0.8683925 \times \frac{HP}{\text{Knots}}$$

Knots (200 - 400)

Hp	200	250	300	350	400
100	163	130	109	93	81
200	326	261	217	186	163
500	815	652	543	465	407
1000	1629	1303	1086	931	815
1500	2444	1955	1629	1396	1222
2000	3259	2607	2172	1862	1629
3000	4888	3910	3259	2793	2444
4000	6517	5214	4345	3724	3259
5000	8147	6517	5431	4655	4073
6000	9776	7821	6517	5586	4888

Knots (500 - 900)

Hp	500	600	700	800	900
1000	652	543	465	407	362
1500	978	815	698	611	543
2000	1303	1086	931	815	724
3000	1955	1629	1396	1222	1086
4000	2607	2172	1862	1629	1448
5000	3259	2715	2327	2037	1810
6000	3910	3259	2793	2444	2172
10,000	6517	5431	4655	4073	3621
12,000	7821	6517	5586	4888	4345
14,000	9124	7603	6517	5703	5069

Knots (1000 - 1800)

Hp	1000	1200	1400	1600	1800
2000	652	543	465	407	362
3000	978	815	698	611	543
4000	1303	1086	931	815	724
5000	1629	1358	1164	1018	905
6000	1955	1629	1396	1222	1086
10,000	3259	2715	2327	2037	1810
12,000	3910	3259	2793	2444	2172
14,000	4562	3802	3259	2851	2534
30,000	9776	8147	6983	6110	5431
40,000	13,035	10,862	9310	8147	7241

$$\text{Thrust Horsepower} = \frac{\text{Thrust (lb)} \times \text{speed (fps)}}{550}$$

$$= \frac{\text{Thrust (lb)} \times \text{speed (mph)}}{375}$$

(Statically 2.6 lb of thrust are equal to 1 hp.)
(Thrust power is a maximum when the missile speed is one half the jet exhaust velocity)
(At a given value of flight speed, the thrust of a turbojet engine can be increased by

a) increasing the jet velocity, V_j
b) increasing the weight flow rate, $\dot{w}$
c) increasing both V_j and $\dot{w}$

SECTION 7.4 ROCKET ENGINES

GENERALIZED ROCKET PROPULSION EQUATIONS

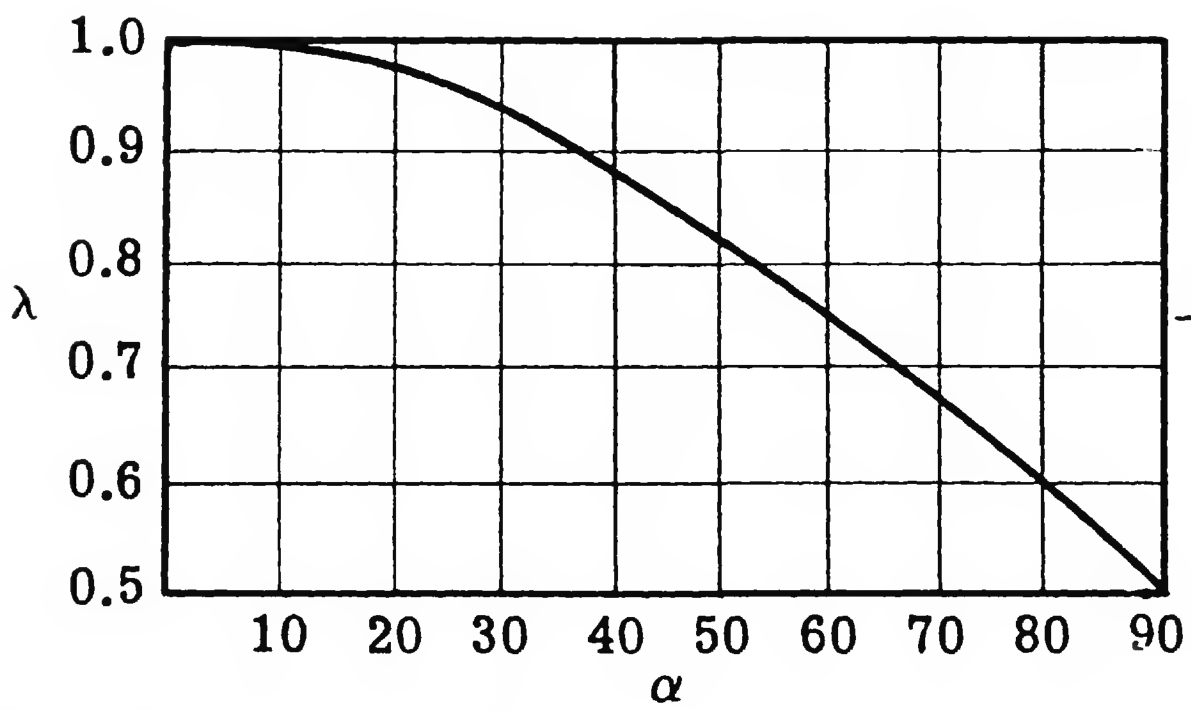
Eq. 7.4.1 Thrust

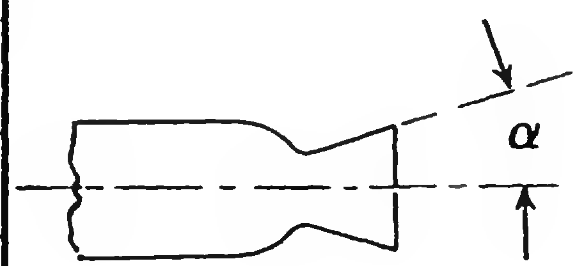
$$F = \frac{\dot{w}}{g}\lambda V_j + (P_e + P_o)\,A_e$$ where λ = divergence coeff., a correction for the exit angle of the exhaust nozzle

The thrust is developed by two parts:

Pressure thrust: $(P_e - P_o)\,A_e$

Velocity Thrust: $\frac{\dot{w}}{g}\lambda V_j$





Eq. 7.4.2 Specific Impulse

$$I_{sp} = \frac{F\Delta t}{W_p} = \frac{F}{\dot{w}} \text{ (sec)}$$

Eq. 7.4.3 Total Impulse

$$I = F\Delta t = W_p I_{sp} \text{ (lb/sec)}$$

Eq. 7.4.4 Effective Exhaust Velocity

$$V_j = g I_{sp} = c^* C_f = \frac{Fg}{\dot{w}}$$

Eq. 7.4.5 Weight Flow Coefficient

$$c_w = \frac{\dot{w}}{p_c A_t}$$

Eq. 7.4.6 Thrust Coefficient

$$C_f = \frac{F}{p_c A_t}$$

Eq. 7.4.7 Characteristic Velocity

$$c^* = \frac{V_j}{C_f} = \frac{g}{\dot{w}} p_c A_t = \frac{g}{c_w}$$

(c^* is a measure of the effectiveness with which the chemical reaction of the propellants produces high temperature, high pressure gases)

GENERALIZED ROCKET PROPULSION EQUATIONS (cont.)

Eq. 7.4.8 Impulse-Weight Ratio

$$R_{I/W} = \frac{I}{W_o}$$

Eq. 7.4.9 Ideal Weight Flow Coefficient

$$c'_w = 0.1443 \frac{\Omega}{\sqrt{T_c/M}} \quad \text{where } \Omega = \sqrt{k}\left(\frac{2}{k+1}\right)^{\frac{k+1}{2(k-1)}}$$

M = molecular weight of gases

Eq. 7.4.10 Ideal Thrust Coefficient

$$C'_f = \lambda\Omega\sqrt{\frac{2k}{k-1}(Z_t)} \quad \text{where } Z_t = 1 - \left(\frac{p_o}{p_c}\right)^{\frac{k-1}{k}} \text{ the expansion factor}$$

Eq. 7.4.11 Ideal Specific Impulse

$$I'_{sp} = \frac{C'_f}{c'_w} = 6.93\,\lambda\sqrt{\frac{T_c}{M}}\sqrt{\frac{2k}{k-1}(Z_t)}$$

where M = molecular weight of gases
C_d = nozzle discharge coeff.

Eq. 7.4.12 Ideal Characteristic Velocity

$$c^{*\prime} = \frac{g}{c'_w} = \frac{gI'_{sp}}{C'_f} = \frac{a_c}{\Omega\sqrt{k}} \quad \text{where } a_c = \sqrt{gkRT_c}$$

Eq. 7.4.13 Calculated Weight Flow Coefficient

$$(c_w)_{calc.} = \frac{\dot{w}}{p_c A_t} = 0.1443\frac{C_d\,\Omega}{\sqrt{\frac{T_c}{M}}}$$

where M = molecular weight of gases
C_d = nozzle discharge coeff.

$$\dot{w} = \frac{A_t p_c C_d}{\sqrt{RT_c}}\sqrt{\frac{2gk}{k-1}}\left(\frac{p_e}{p_c}\right)^{\frac{1}{k}}\sqrt{Z_t}$$

Eq. 7.4.14 Calculated Thrust Coefficient

$$(C_f)_{calc.} = \lambda C_d\,\varphi\,\Omega\sqrt{\frac{2k}{k-1}(Z_t)} + \left(\frac{p_e}{p_c} - \frac{p_o}{p_c}\right)\frac{A_e}{A_t}$$

Eq. 7.4.15 Calculated Specific Impulse

$$(I_{sp})_{calc.} = 6.93\,\lambda\varphi\sqrt{\frac{T_c}{M}}\sqrt{\frac{2k}{k-1}(Z_t)}$$

φ = 0.93 to 0.99 - determined experimentally (use 0.95 for design)

Eq. 7.4.16 Input Energy

$$E = (\dot{w}_o + \dot{w}_f)\left(J\Delta H_p + \frac{V^2}{2g}\right)$$

where ΔH_p = calorific value of propellant, Btu/lb.

Eq. 7.4.17 Overall Efficiency

$$\eta_o = \frac{2\nu}{1+\nu^2}\left[\frac{P}{w_p\left(J\Delta H_p + \frac{V^2}{2g}\right)}\right]$$

SOLID ROCKET DESIGN EQUATIONS

Eq. 7.5.1 Specific Impulse

$$I_{sp} = \frac{F}{\dot{w}} = \frac{F\Delta t}{W_p} = \frac{c^* C_f}{g} = \frac{V_j}{g} = \frac{C_f}{c_w}$$

Eq. 7.5.2 Total Impulse

$$I = Ft \text{ (for constant } F) = W_p I_{sp}$$

Eq. 7.5.3 Over-all Impulse

$$I_o = \frac{Ft}{W_o}$$

Eq. 7.5.4 Characteristic Velocity

$$c^* = \frac{I_{sp}\, g}{C_f} = \frac{g}{\dot{w}} p_c A_t = \frac{g}{c_w} = \frac{V_j}{C_f}$$

Eq. 7.5.5 Exhaust Velocity

$$V_j = g I_{sp}$$

Eq. 7.5.6 Weight Flow

$$\dot{w} = A_p \gamma_p p_c a_2 = r_o A_p \gamma_p = c_w p_c A_t$$

Eq. 7.5.7 Thrust Coefficient

$$C_f = \frac{F}{p_c A_t} = \frac{V_j}{c^*}$$

Eq. 7.5.8 Weight Flow Coefficient

$$c_w = \frac{\dot{w}}{p_c A_t}$$

Eq. 7.5.9 Linear Burning Rate

$$r_o = a_2 p_c^n = \frac{\dot{w}}{A_p \gamma_p}$$

Eq. 7.5.10 Area Ratio

$$K_n = \frac{A_p}{A_t} = \frac{c_w p_c^{1-n}}{a_2 \gamma_p}$$

Eq. 7.5.11 Chamber Pressure

$$p_c = \left(\frac{K_n a_2 \lambda_p'}{c_w}\right)^{\frac{1}{1-n}}$$

Eq. 7.5.12 Impulse-Weight Ratio

$$R_{I/W} = \frac{I}{W_o}$$

Eq. 7.5.13 Pressure Sensitivity to Temperature

$$\Phi_p = \frac{(\Delta n)(p_c)}{\Delta T}$$

FIGURE 7.5.1 SOLID PROPELLANT JATO NOMENCLATURE

(Jet Assisted Takeoff)

Basic Name, Description, and Identification

The Basic Name is the abbreviation, JATO. The Description is composed of three sub-parts: (1) numerals denoting thrust duration in seconds (at 70°F); (2) two letter symbols denoting the type and physical state of propellant followed by a dash; and (3) numerals denoting the approximate thrust in pounds produced by the unit (at 70°F). The Identification consists of various symbols and numerals used to define status; experimental or standard; and model or design sequence. There are relatively minor variations in the identifications used in common by the Army and Air Force and those used by the Navy.

The letter symbols for the type of propellant, the first of the two symbols denoting propellant type and physical state, are:

Symbol	Type
A	Acid with fuel, or asphalt with perchlorate
B	Ball or chopped double base
C	Composite (picrate-nitrate)
D	Cast double base (May contain composite strands or particles)
E	Extruded double base
F	Furfuryl alcohol with oxidizer (includes all alcohols higher than ethyl)
H	Hydride fuels
K	Cast perchlorates (binder fuels other than asphalt)
N	Nitrates and nitro-compounds other than those designated above
O	Liquid oxygen with alcohol or other hydrocarbons

The letter symbols for the physical state of the propellant at ordinary temperatures, the second of the two symbols, are:

Symbol	Type
L	Liquids
P	Plastic compositions (can be deformed under moderate stress)
S	Solids (not readily deformable)

FIGURE 7.5.2 PROPERTIES OF TYPICAL SOLID PROPELLANTS

Propellant Type	Composite	Composite	Composite
METHOD OF MANUFACTURE	Cast	Cast	Cast
OXIDIZER	Ammonium perchlorate	Ammonium nitrate	Ammonium perchlorate
FUEL	Polybutadiene -Acrylic Acid plus Aluminum powder	Cellulose Acetate	Polyurethane
CHAMBER PRESSURE, p_c, psi RANGE	15 to 2000	15 to 2000	15 to 2000
CHARACTERISTIC VELOCITY, c* fps	5140	3500	4810
THEORETICAL SPECIFIC IMPULSE I_{sp} AT SEA LEVEL, lb sec/lb $p_c = 1000$ psi	250	171	238
BURNING RATE, r_o in./sec AT $p_c = 1000$ psi	0.467	0.086	0.227
EXPONENT, n, IN BURNING RATE EQUATION $r_o = a_2 p_c^n$	0.236	0.50	0.05
TEMPERATURE COEFFICIENT OF PRESSURE, $\pi_K = \frac{1}{p_c}\left(\frac{Sp}{\delta T}\right)_K$, (%/°F)	0.115	0.26	0.13
DENSITY δ_p lb/cu in.	0.063	0.056	0.062

FIGURE 7.5.2 PROPERTIES OF TYPICAL SOLID PROPELLANTS

Composite	Composite	Double-Base	Double-Base	Double-Base	Double-Base
Cast	Cast	Extruded	Cast	Cast	Cast
Ammon. perch.+ Potassium perch.	Potassium Perchlorate	Nitrocellulose Nitroglycerin	Nitrocellulose Nitroglycerin	Ballistite	Cordite
Poly-urethane	Polyester-styrene				
200 to 1800	400 to 2000	500-20000	300-4200	1000-300	1000-3000
4700	3600	4350	4450		
236	178	216(1)	219	200	180
0.479	0.69	0.46	0.45	--	
—	0.74	0.00(2)	0.61(1)	0.85	0.77
0.22	0.33	0.09	--		
0.063	0.068	0.056	0.057	0.043-0.061	
		(1) at 1300 psi (2) Between 900-1200 psi	(1) Between 800-1650 psi		

FIGURE 7.5.2 PROPERTIES OF TYPICAL SOLID PROPELLANTS (cont.)

Parameters	Symbol
Total impulse to loaded weight ratio	I/W_0
Thrust to weight ratio	F/W_0
Specific impulse (at sea level)	I_{sp}

Propellant	Type	Pressure Range (psi)	Low Pressure Limit (psi)	I_{sp} (sec)
Ballistite	Double base	1000-3000	200	200
Black powder	Composite	100-1000	15	70
Cordite	Double-base	1000-3000	300	180
GALCIT 161	Composite	1300-3700	700	190
LOX-Rubber	Liquid-solid	100-500	15	225
NDRC EJA	Composite	600-1000	—	180
WASAG DEGN	Homogeneous	700-4000	700	180

FIGURE 7.5.2 PROPERTIES OF TYPICAL SOLID PROPELLANTS (cont.)

Typical Values
50 lb-sec/lb for poorly designed rockets; 100 to 130 lb-sec/lb for highly stressed hardware and effective volume utilization
200 for high thrust units; 100 for low thrust units
170 to 230 sec depending on propellant combination, chamber pressure, ambient pressure, and nozzle area ratio

n	r_o (in. per sec)	Φ_p (per cent deg F)	γ (lb/cu ft)	Exhaust
0.85	—	0.5-1.3	75-105	High flash, black smoke
0.5-0.8	0.1-0.5	—	75-130	Gray smoke
0.77	—	0.7	—	High flash, black smoke
0.75	1.4-1.5	0.23	110	White smoke
—	—	—	—	Smokeless
0.45	0.2-1	0.2-0.3	—	Gray smoke
0.73	0.2-0.8	—	—	High flash, black smoke

LIQUID ROCKET DESIGN EQUATIONS

Eq. 7.6.1 Specific Impulse

$$I_{sp} = \frac{F}{\dot{w}} = \frac{F\Delta t}{W_p} = \frac{V_j}{g} = \frac{C_f}{c_w}$$

Eq. 7.6.2 Total Impulse

$$I = Ft \text{ (for constant F)}$$

Eq. 7.6.3 Thrust

$$F = C_f\, p_c A_t$$

Eq. 7.6.4 Thrust at Altitude

$$F_{alt} = F_{sl} + A_e (P_{sl} - P_{alt})$$

Eq. 7.6.5 Density Impulse

$$I_D = I_{sp} d$$

Eq. 7.6.6 Specific Gravity of Propellant

$$d_p = \frac{r + 1}{\frac{r}{d_o} + \frac{1}{d_f}}$$

where d_o = density of oxidizer
d_f = density of fuel

Eq. 7.6.7 Mixture Ratio

$$r = \frac{\dot{w}_o}{\dot{w}_f}$$

Eq. 7.6.8 Propellant Weight Flow

$$\dot{w}_p = \dot{w}_o + \dot{w}_f$$

Eq. 7.6.9 Thrust Coefficient

$$C_f = \sqrt{\frac{2k^2}{k - 1}\left(\frac{2}{k + 1}\right)^{\frac{k+1}{k-1}}\left[1 - \left(\frac{P_e}{p_c}\right)^{\frac{k-1}{k}}\right]} + \frac{P_e - P}{p_c}\left(\frac{A_e}{A_t}\right)$$

Eq. 7.6.10 Characteristic (exhaust) Velocity

$$c^* = \frac{p_c A_t g}{\dot{w}_p} = \frac{V_j}{C_f} = \frac{g}{c_w}$$

$$c^* = \frac{\sqrt{gkR\frac{T_c}{M_o}}}{k\left(\frac{2}{k + 1}\right)^{\frac{k+1}{2(k-1)}}}$$

Eq. 7.6.11 Characteristic Length

$$L^* = \frac{V_c}{A_t}$$

Eq. 7.6.12 Stay Time of Gases in Combustion Chamber

$$t_c = \frac{V_c}{\dot{w}_p\, \nu_1} = \frac{V_c\, p_c}{12\, \dot{w}_p\, R\left(\frac{T_c}{M_o}\right)}$$

FIGURE 7.6.1 TYPICAL VALUES OF CHARACTERISTIC CHAMBER LENGTH (L*)

(at p_c = 300 psia)

Propellants	L* (in.) (Approx. Values)
Liquid oxygen-alcohol	50-100
Nitric acid-aniline	40-175
Nitric acid-JP-3	50-60
Nitromethane	>190
Liquid oxygen-JP-4	35-55

$$L^* = \frac{\text{Volume of combustion chamber}}{\text{Area of nozzle throat}}$$

FIGURE 7.6.2 SPECIFIC GRAVITIES OF LIQUID ROCKET PROPELLANTS

(From G. P. Sutton, "Rocket Propulsion Elements", 1956. Copyright John Wiley & Sons, Inc., New York)

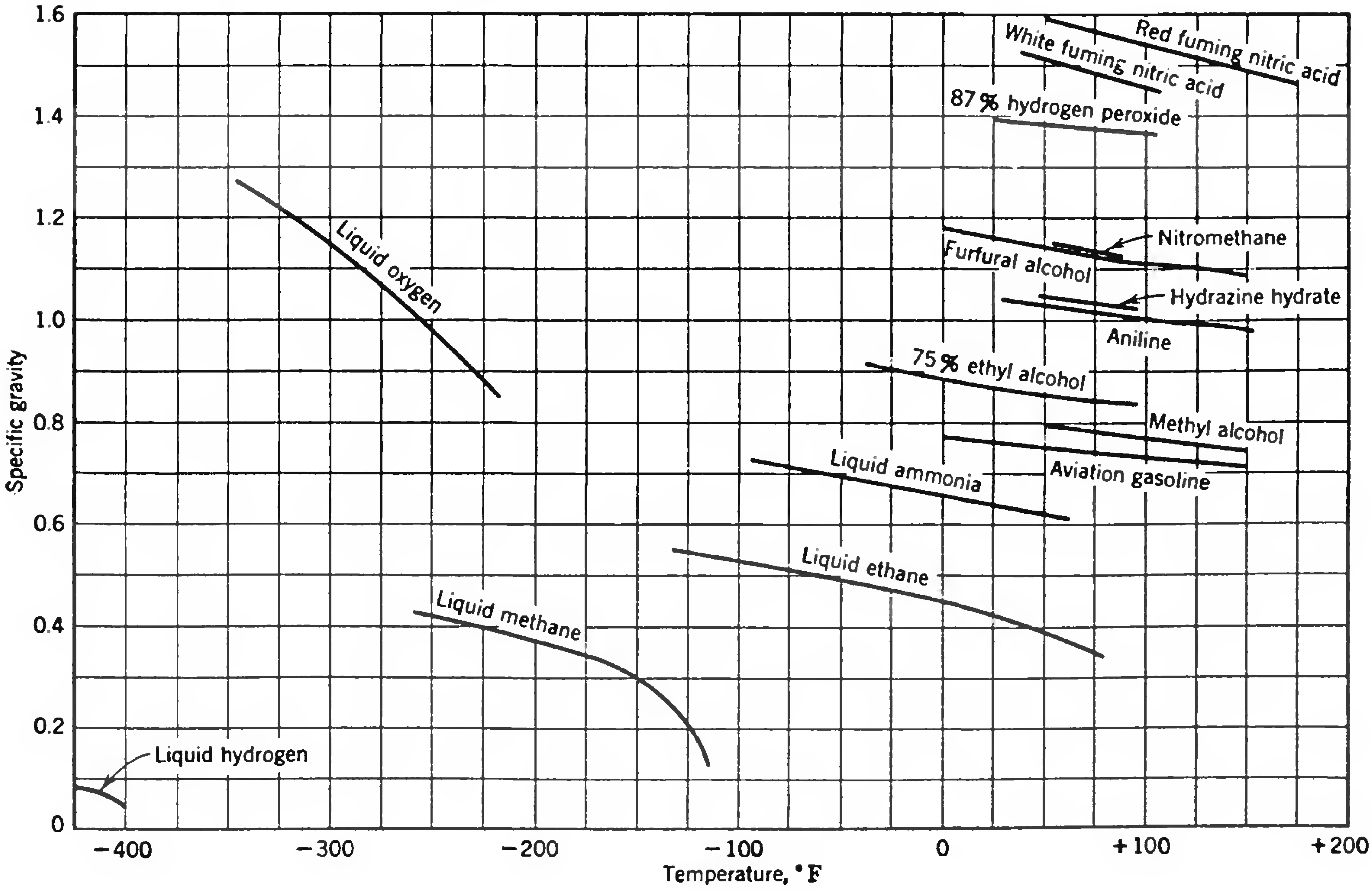


FIGURE 7.6.3 SOME PHYSICAL PROPERTIES OF LIQUID ROCKET PROPELLANTS

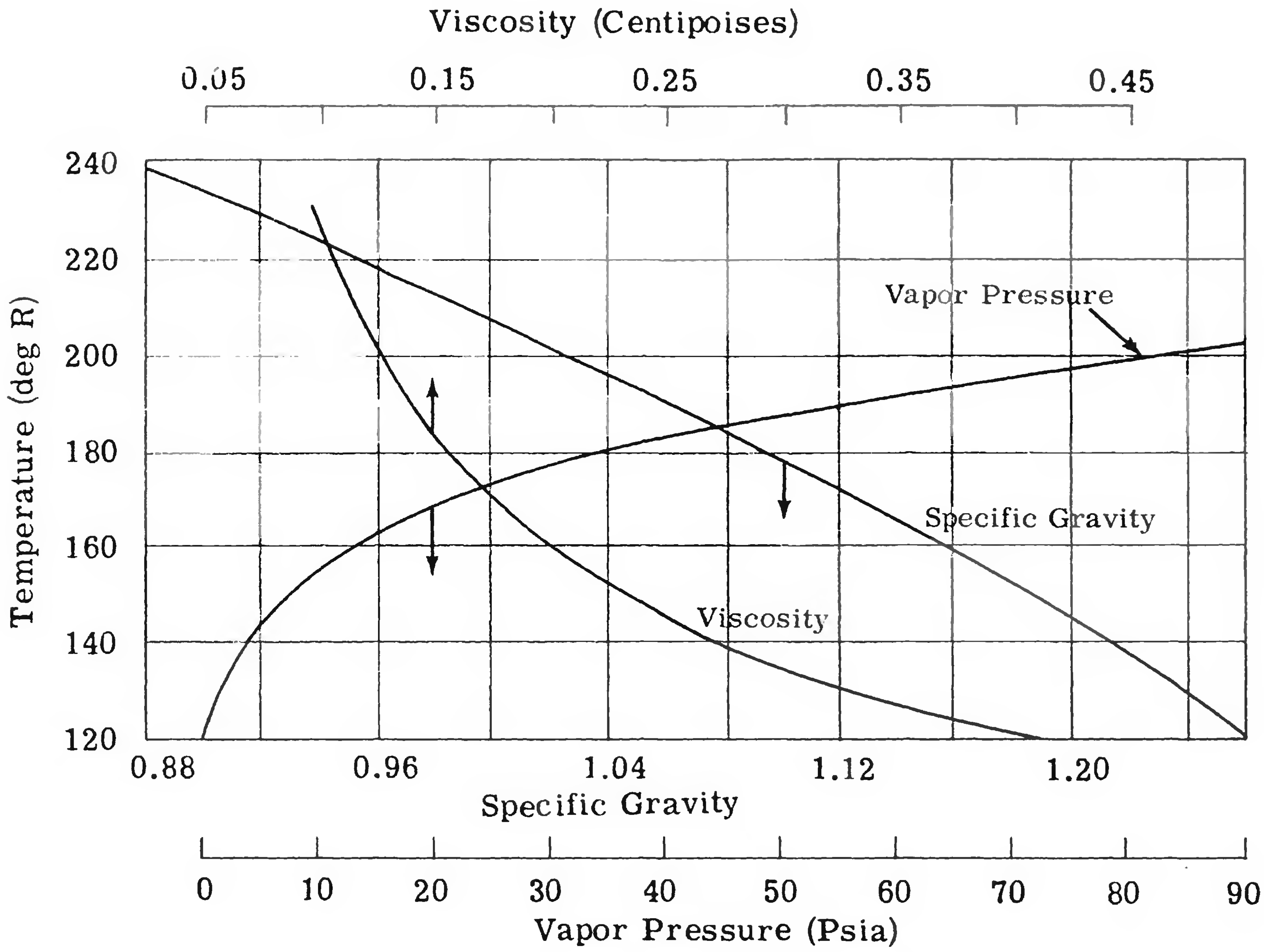
(From G. P. Sutton, "Rocket Propulsion Elements", 1956, Copyright John Wiley & Sons, Inc., New York)

Propellant	Aluminum Borohydride	Chlorine Trifluoride	Diethylene Triamine	Ethyl Nitrate	Ethylene Oxide	Fluorine	Hydrazine Hydrate	Isopropyl Alcohol
Chemical formula	$Al(BH_4)_3$	ClF_3	$NH_2CH_2CH_2$— —$NHCH_2CH_2NH_2$	$C_2H_5NO_3$	C_2H_4O	F_2	$N_2H_4 \cdot H_2O$	$CH_3CHOHCH_3$
Molecular weight, lb/mole	71.526	92.457	103.1	91.07	44.05	38.0	50.06	60.094
Melting point, °F	−84.1	−117.4	< −38	−151.6	−170.5	−361	−40	−129
Boiling point, °F	113	52.34	404	191.66	51.1	−306.3	245.3 (739 mm Hg)	180.2
Heat of vaporization at 1 atm, Btu/lb	181.2	....	....	....	250 (77° F)	73.89 (−306.3° F)	....	286.2 (180.2° F)
Heat of formation, Btu/lb-mole	....	−76,932 (liquid, 77° F)	....	−82,440 (77° F)	−32,920 (liquid, 77° F)	0	−104,310 (77° F)	−135,980 (77° F)
Specific heat, Btu/lb °F	....	....	....	0.447 (77° F)	0.471 (50° F)	0.36 (−320° F)	....	0.596 (68° F)
Density, lb/ft³	36 (32° F)	112 (32° F)	59.18 (77° F)	69.86 (59° F) 68.99 (68° F)	56.0 (32° F) 55.1 (50° F)	97 (−320° F)	65.5 (32° F) 64.4 (68° F)	50.01 (32° F) 49.01 (68° F)
Viscosity centipoises	....	....	6.6 (70° F) 0.2 (165° F)	....	0.58 (−58° F) 0.32 (32° F)	....	3.5 (32° F) 2.0 (68° F)	3.8 (32° F) 2.3 (68° F) 1.765 (86° F)
Shock sensitivity	Insensitive	....	Insensitive	Explosively sensitive	Liquid stable	Insensitive	Insensitive	Insensitive
Color	Colorless	Pale green	Slightly brown	Colorless	Colorless	Yellow-green	Colorless	Colorless
Effect on metals	Inert to glass, stainless steel, and iron	Very corrosive; inert to mild steel, if clean	Keep away from copper and alloys	Slightly corrosive	Non-corrosive	Must passivate most metals; nickel and monel are good	Slightly corrosive	Non-corrosive
Effect on most organic material (grease, oil, skin, etc.)	Burns skin, will react with organic material containing moisture in traces	Burns eyes and skin; reacts violently with most materials	Solvent action on many	Solvent	Solvent action on some, many unaffected	Violently reactive	....	Solvent
Fire hazard	Ignites spontaneously in air containing moisture	Reacts violently with water and many other compounds	Low	Flammable, dangerous	High	Very high	Dangerous	High
Toxicity	Inhalation causes chills and fever	Very high	Low	....	Medium	Very high	Toxic vapors	Mild
Stability, thermal	Decomposes slowly at room temperature	Begins to decompose at 570° F	Stable	Explosively sensitive	Sensitive; good below 86° F	Stable if clean	Explosive at 62 ° F	Stable to 1112° F

FIGURE 7.6.3 SOME PHYSICAL PROPERTIES OF LIQUID ROCKET PROPELLANTS (cont.)

Propellant	Methane	Methyl Amine	Nitrogen	Nitrogen Tetroxide	Nitro-glycerine	Ozone	Propane	n-Propyl Nitrate	Turpentine
Chemical formula	CH_4	CH_3NH_2	N_2	N_2O_4	$C_3H_5(NO_3)_3$	O_3	C_3H_8	$C_3H_7NO_3$	$\sim C_{10}H_{16}$
Molecular weight, lb/mole	16.04	31.058	28	92.02	227.094	48	44.094	105.094	~132
Melting point, °F	−299.2	−136.2	−346	12 (139.78 mm Hg)	55.76	−315.4	−305.8	<−150	−148
Boiling point, °F	−259	20.6	−321	70	500 (extrapolated)	−169.5	−43.7	220 (initial)	318
Heat of vaporization at 1 atm, Btu/lb	248.4 (−254.2° F)	370.9	86.04 (−320° F)	168.1 (69.4° F)	....	136.08 (−169.5° F)	183	164 (68° F)	123.5 (312.8° F)
Heat of formation, Btu/lb-mole	−32,200 (gas, 77° F)	−13,140	0	−12,240 (liquid, 77° F)	−159,840 (68° F)	−61,920 (gas, 77° F)	−51,555 (liquid, 77° F)	−88,280	....
Specific heat, Btu/lb °F	....			....		....	0.576 (32° F)	0.419 (77° F)	~0.42 (68° F)
Density, lb/ft³	22.16 (−184° F) 17.92 (−139° F)	43.7 (0° F)	50.44 (−321° F)	90.52 (63° F)	99.51 (68° F)	....	36.54 (−48° F)	66.17 (−68° F)	55.56 (32° F) 54.56 (68° F)
Viscosity centipoises	0.185 (−292° F) 0.140 (−274° F) 0.115 (−256° F)	0.236 (32° F)	....	0.44 (59.65° F)	36.0 (68° F) 21.0 (86° F)	~1.55 (−297.4° F) 4.2 (319° F)	8.78 (−301° F) 0.216 (−49° F)	0.69 (68° F)	~1.78 (50° F) ~1.49 (68° F)
Shock sensitivity	Insensitive	Insensitive	Insensitive	Insensitive	Very sensitive to percussion	....	Insensitive	Low sensitivity	Insensitive
Color	Colorless	....	Colorless	Yellow to red	....	Colorless to blue	Colorless	Colorless to light straw	Colorless when pure
Effect on metals	Non-corrosive	Use stainless steel; avoid copper	Non-corrosive	Corrodes steel when wet	....	....	Non-corrosive	Relatively non-corrosive, avoid copper and nickel	Non-corrosive
Effect on most organic material (grease, oil, skin, etc.)	Solvent	Reactive	None	Reacts with many	....	Explosive with many	Solvent	Solvent	Solvent
Fire hazard	High	High	None	Low	High	Very high	High	Low	Fairly high
Toxicity	Asphyxiant	Mild	Non-toxic	Very toxic	High	Very Toxic	Mild anaesthetic	Low	Non-toxic
Stability, thermal	Stable	Stable	Stable	Stable at room temp.	Stable	Explosively unstable	Stable	Stable	Stable

FIGURE 7.6.4 PROPERTIES OF LIQUID OXYGEN



Physical Constants

Boiling Point	162.6 deg R
Critical Temperature	278.0 deg R
Critical Pressure	49.7 atm

Specific Heat (103 deg R - 131 deg R): $0.398 \frac{\text{Btu}}{\text{lb-deg F}}$

Thermal Conductivity (132 deg R): $0.121 \frac{\text{Btu-ft}}{\text{hr-ft}^2\text{-deg F}}$

Latent Heat of Vaporization (162 deg R): $2930 \frac{\text{Btu}}{\text{lb-mol}}$

FIGURE 7.6.5 THEORETICAL PERFORMANCE OF SEVERAL ROCKET PROPELLANT COMBINATIONS

Oxidizer	Fuel	Specific Impulse, I_{sp}, sec.	Specific Impulse x Bulk Density. I_{sp} x d, sec x gram/cc	Mixture Ratio	Theor. Combustion Temp., °F	Ratio Specific Heats, $k = \frac{c_p}{c_v}$	Avg. Molecular Wght. of Comb. Prod.	Bulk Density, gram/cc	Exhaust Velocity, fps
Bromine Pentafluoride	Ammonia	235	422	6.0	6660	1.34	29	1.80	7560
85% Chlorine Heptoxide + 15% Nitrogen Tetroxide	Turpentine	250	345	2.8	5900	1.27	24	1.39	8040
Chlorine Trifluoride	Ammonia	240	303	3.0	4980	1.32	22	1.26	7620
	Hydrazine	253	356	2.5	6000	1.33	23	1.46	8140
Fluorine	Ammonia	305	352	3.0	7270	1.33	19	1.16	9820
	Diborane	308	328	5.0	7880	1.30	21	1.07	9910
	Hydrazine	316	410	2.0	7740	1.33	19	1.30	10160
	Hydrogen (Max. I_{sp}d)	337	253	19.0	8530	1.34	18	0.75	10840
	Hydrogen (Max. I_{sp})	373	118	4.5	5000	1.33	8.9	0.32	12000
	JP-4	280	335	2.9	7100	1.22	24	1.19	9010
50% Fluorine + 50% Nitrogen Trifluoride	Ammonia	293	337	2.8	6540	1.32	19	1.15	9420

FIGURE 7.6.5 THEORETICAL PERFORMANCE OF SEVERAL ROCKET PROPELLANT COMBINATIONS (cont.)

Oxidizer	Fuel	Specific Impulse, I_{sp}, sec.	Specific Impulse x Bulk Density. $I_{sp} \times d$, sec x gram/cc	Mixture Ratio	Theor. Combustion Temp., °F	Ratio Specific Heats, $k = \frac{c_p}{c_v}$	Avg. Molecular Wght. of Comb. Prod.	Bulk Density, gram/cc	Exhaust Velocity, fps
Oxygen Difluoride	Hydrazine	295	365	1.1	6380	1.28	18	1.23	9490
	Ammonia	292	310	1.9	6040	1.29	18	1.07	9400
	n-Octane	300	366	3.8	7340	1.33	20	1.22	9650
RFNA ($22\%\ NO_2$)	Polyethylene	236	330	4.5	5320	1.22	25	1.40	7600
	JP-4	238	307	4.1	5150	1.23	25	1.30	7660
	80% Diethylenetriamine + 20% Methylamine	243	321	3.0	5250	1.23	24	1.33	7820
	Unsymmetrical Dimethyl-Hydrazine	249	305	2.6	5200	1.23	22	1.23	8020
Nitrogen Tetroxide	Hydrazine	263	314	1.1	4950	1.26	19	1.20	8460
ON 7030 (70% Nitrogen Textroxide + 30% Nitric Oxide)	Triethyl- Trithiophosphite	233	296	2.5	6000	1.23	30	1.28	7500
	Methyl Alcohol	239	263	2.1	5210	1.22	25	1.10	7700
	50% Ammonia + 50% Methyl Alcohol	245	258	2.1	5050	1.23	23	1.06	7880
	63% Triethylamine + 37% Orthotoluidine	246	293	3.7	5800	1.24	25	1.19	7920

ON 7030 (70% Nitrogen Textroxide + 30% Nitric Oxide) (cont.)	Turpentine	250	301	3.5	5800	1.25	24	1.21	8040
	Ammonia	250	258	2.1	4900	1.23	21	1.03	8040
	Ethylene Oxide	250	285	2.0	5730	1.24	24	1.14	8040
Oxygen	Ethyl Silicate	244	256	1.6	5700	1.21	26	1.05	7780
	75% Ethyl Alcohol	243	246	1.3	5150	1.22	23	0.99	7920
	Methyl Alcohol	237	250	1.2	5230	1.21	22	0.95	8040
99.6% Hydrogen Peroxide	92.5% Ethyl Alcohol	242	299	4.0	4600	1.20	23	1.24	7790
	JP-4	247	316	6.5	4830	1.20	22	1.28	7940
	Hydrazine	262	324	1.7	4690	1.22	19	1.24	8430
90% Hydrogen Peroxide	Hydrazine	252	301	1.5	4170	1.25	18	1.20	8110
54% Hydrogen Peroxide + 40% Ammonium Nitrate + 6% Water	Kerosene	232	310	9.0	4270	1.21	22	1.34	7460
100% Nitric Acid	Turpentine	235	308	4.4	4950	1.22	25	1.32	7560
95% Nitric Acid	Butyl Mercaptan	223	285	4.0	4780	1.22	27	1.28	7180

FIGURE 7.6.5 THEORETICAL PERFORMANCE OF SEVERAL ROCKET PROPELLANT COMBINATIONS (cont.)

Oxidizer	Fuel	Specific Impulse, I_{sp}, sec.	Specific Impulse x Bulk Density. I_{sp}x d, sec x gram/cc	Mixture Ratio	Theor. Combustion Temp., F	Ratio Specific Heats, $k = \frac{c_p}{c_v}$	Avg. Molecular Wght. of Comb. Prod.	Bulk Density, gram/cc	Exhaust Velocity, fps
RFNA (6.5% NO_2)	n-Octane	236	296	4.5	5100	1.24	24	1.26	7600
RFNA (15% NO_2)	Hydrazine	257	322	1.3	4980	1.25	20	1.26	8270
RFNA (22% NO_2)	Triethyl Trithio Phosphite	224	318	3.0	5520	1.21	30	1.43	7210
	Ammonia	236	262	2.15	4220	1.24	21	1.12	7600
	Turpentine	236	321	4.2	5400	1.22	26	1.36	7600
Oxygen	Nitroethane	251	271	0.65	5570	1.23	23	1.09	8080
	92.5% Ethyl Alcohol	246	252	1.5	5400	1.21	23	0.98	8110
	Nitropropane	255	269	0.9	5620	1.23	23	1.06	8210
	Isopropyl Alcohol	250	258	1.7	5560	1.22	22	0.98	8300
	Propylene Oxide	257	258	1.6	5900	1.23	23	1.00	8300
	69.5% Propylene Oxide + 30.5% Ethylene Oxide	257	260	1.5	5900	1.23	23	1.00	8360

Oxygen (cont.)	Ethylene Oxide	257	262	1.1	5750	1.24	22	0.99	8430
	JP-4 (C/H = 6.85)	255	263	2.2	5880	1.24	22	0.98	8460
	JP-4 (C/H = 6.00)	256	263	2.3	5770	1.24	22	0.98	8460
	88% Ethylene Diamine	263	273	1.4	6000	1.23	19	1.04	8460
	Turpentine	262	270	2.4	5880	1.23	22	1.04	8430
	Ammonia	232	264	1.3	4940	1.23	19	0.88	8500
	Methyl Cyclo-Pentane	257	264	2.3	5770	1.24	22	0.98	8500
	n-Octane	254	266	2.4	5790	1.23	22	0.96	8560
	Diethylene-triamine	266	281	1.5	5550	1.24	21	1.06	8560
	Methylamine	247	271	1.6	5460	1.22	20	0.91	8720
	Methyl Acety-lene	251	272	2.0	6180	1.27	22	0.93	8750
	Unsymmetrical Dimethyl Hydrazine	261	274	1.4	5650	1.24	20	0.96	8820

FIGURE 7.6.5 THEORETICAL PERFORMANCE OF SEVERAL ROCKET PROPELLANT COMBINATIONS (cont.)

Oxidizer	Fuel	Specific Impulse, I_{sp}, sec.	Specific Impulse x Bulk Density. I_{sp}x d, sec x gram/cc	Mixture Ratio	Theor. Combustion Temp., °F	Ratio Specific Heats, $k = \frac{c_p}{c_v}$	Avg. Molecular Wght. of Comb. Prod.	Bulk Density, gram/cc	Exhaust Velocity, fps
Oxygen (cont.)	Hydrazine	279	295	0.75	5370	1.25	18	1.06	8980
	Hydrogen (Max. I_{sp}d)	135	316	8.0	5870	1.22	16	0.43	10160
	Hydrogen (Max. I_{sp})	93	363	3.5	4500	1.26	9	0.26	11680
70% Oxygen + 30% Ozone	JP-4	268	278	2.3	5950	1.24	22	1.04	8620
30% Oxygen + 70% Ozone	JP-4	273	294	2.3	6180	1.25	21	1.08	8780
100% Ozone	JP-4	280	318	2.4	6380	1.25	21	1.14	9010
Tetranitromethane	Hydrazine	260	335	1.4	5250	1.27	20	1.29	8360

CONDITIONS FOR FIGURE 7.6.5

1. Combustion chamber pressure = 500 psia
2. Nozzle exit pressure = 14.7 psia
3. Optimum nozzle expansion ratio $= \frac{\text{exit area}}{\text{throat area}}$
4. Contraction ratio $\frac{\text{chamber area}}{\text{throat area}}$, assumed to be infinite
5. Adiabatic combustion
6. Insentropic expansion of ideal gas
7. Compositions expressed in weight percent
8. The composition of the combustion products was assumed to be frozen at chamber conditions. If shifting equilibrium were assumed during expansion, the theoretical specific impulse would be 3 to 10 percent higher. The most important parameter determining this increase is the combustion temperature, the increase being greater at higher temperatures.
9. d = Bulk density, g/cc, at 80 F* of propellant combination at given mixture ratio.

$$d = \frac{r + 1}{\frac{r}{d_{oxidizer}} + \frac{1}{d_{fuel}}}$$

10. To convert I_{sp} and $I_{sp}d$ to other chamber pressures:

Pressure	Multiply By
200	0.89
300	0.94
400	0.98
500	1.00
600	1.02
700	1.03
800	1.05
900	1.06
1000	1.07
1100	1.09
1200	1.10

* The density at the boiling point was used for those oxidizers or fuels which boil below 80F at one atmosphere pressure.

FIGURE 7.6.6 COMPARISON OF TYPICAL LIQUID AND SOLID PROPELLANTS

Parameters	Liquid Propellant	Solid Propellant
I_{sp}, Specific impulse (lb-sec/lb)	200-260	190-220
p_c, Combustion pressure (psi)	300-500	500-1500
T_c, Combustion temperature (deg F)	3000-5000	2000-5000
r_o, Burning rate (ips)	2-10*	0.1-2
γ, Propellant density (lb/cu ft)	65-95	95-120
Impulse-volume ratio (lb-sec/cu ft)	1980 †	2500
Cost (per lb-sec)	\$0.003 †	\$0.003-0.03
I_o, Total impulse/total weight (lb-sec/lb)	160†	50-175

* nitric acid-butyl mercaptan
† liquid oxygen-gasoline

FIGURE 7.6.7 CONVERSION FACTORS FOR LIQUID AND GASEOUS OXYGEN

Weight of Liquid or Gas	Volume of Liquid at Normal Boiling Point			Volume of Gas at 70°F
Pounds	Cu Ft	Quarts	Gallons	Cu Ft
1.000	0.014	0.419	0.105	12.07
2.205	0.031	0.924	0.231	26.62
71.4	1.00	29.9	7.48	862.00
2.52	0.035	1.06	0.264	30.5
2.39	0.033	1.00	0.250	28.8
9.55	0.134	4.0	1.00	115.0
8.284	0.116	3.47	0.868	100.0
2.925	0.041	1.23	0.306	35.31

FIGURE 7.6.8 CONVERSION FACTORS FOR LIQUID AND GASEOUS NITROGEN

Weight of Liquid or Gas	Volume of Liquid at Normal Boiling Point			Volume of Gas at 70°F
Pounds	Cu Ft	Quarts	Gallons	Cu Ft
1.000	0.020	0.593	0.148	13.80
2.205	0.044	1.31	0.327	30.41
50.5	1.00	29.9	7.48	696.00
1.78	0.035	1.06	0.264	24.6
1.69	0.033	1.00	0.250	23.7
6.75	0.134	4.00	1.00	93.1
7.250	0.144	4.30	1.07	100.0
2.560	0.051	1.52	0.379	35.31

SECTION 8—SPACE FLIGHT DATA

GENERALIZED VERTICAL TRAJECTORY EQUATIONS

See Section 7 for notations.

Assuming constant gravitational acceleration and no drag:

Eq. 8.1. Velocity at cutoff (end of burning time)

$$v_c = g\ I_{sp} \left(\log N - \frac{N - 1}{AN}\right)$$

Eq. 8.2. Altitude at cutoff

$$h_c = g(I_{sp})^2\ \frac{N - 1}{AN} \left[1 - \frac{\log N}{N - 1} - \frac{1}{2}\frac{N - 1}{AN}\right]$$

Eq. 8.3. Peak altitude

$$h_p = g(I_{sp})^2 \left[\frac{(\log N)^2}{2} - \frac{1}{A}\left(\log N - \frac{N - 1}{N}\right)\right]$$

Eq. 8.4. Height from cutoff to peak altitude

$$h_{p-c} = \frac{g}{2}\ (I_{sp})^2 \left(\log N - \frac{N - 1}{AN}\right)^2$$

Eq. 8.5. Time of powered flight

$$t = \frac{N - 1}{AN}\ I_{sp}$$

Eq. 8.6. Escape velocity

$$v_e = R_e \sqrt{\frac{2g_e}{R_e + h}}$$

Eq. 8.7. Satellite velocity

$$v_s = R_e \sqrt{\frac{g_e}{R_e + h}}$$

Eq. 8.8. Period of revolution of circular satellite relative to earth

$$t = 2\pi\ \frac{(R_e + h)}{v_s}$$

t = time for one revolution

Eq. 8.9. Variation of gravity with altitude

$$g_h = g_e \left(\frac{R_e}{R_e + h}\right)^2$$

FIGURE 8.1 MASS RATIOS & FACTORS FOR A MULTISTAGE ROCKET PROPELLED MISSILE

Velocity	Mass Empty		Mass At Takeoff	Structural Factor, ϵ	Payload Ratio, λ	Effective Mass Ratio, r	Velocity Increase
v_n	[m_u = payload] m_n	Last Stage	M_n	$\frac{m_n - m_u}{M_{on} - m_u}$	$\frac{m_u}{M_{on}}$		Total $= v_1 + v_2 \ldots + v_n$
	m_{n-1}		M_{n-1}				
	m_{k+1}		M_{k+1}	$\frac{M_{k+1}}{M_{k+1}}$			
v_k	$m_k = M_k - m_{p_k}$	General Stage	$M_k\ r_{e_k}$	$\frac{m_k}{M_k} = 1 - y_k$	$\frac{\sum_{k+1}^{n} M}{\sum_{k}^{n} M}$	$\frac{\sum_{k}^{n} M}{m_k + \sum_{k+1}^{n} M}$	$-\bar{v}_{j_k} \log_e \left(\frac{1}{r_{e_k}}\right) - \bar{g}_k \tau_{p_k}$
v_2	m_2	Second Stage	$M_2\ r_{e_2}$	$\frac{m_2}{M_2}$	$\frac{M_3 + M_4 \ldots + M_n}{M_2 + M_3 \ldots + M_n}$	$\frac{M_2 + M_3 \ldots + M_n}{m_2 + M_3 \ldots + M_n}$	$-\bar{v}_{j_2} \log_e \left(\frac{1}{r_{e_2}}\right) - \bar{g}_2 \tau_{p_2}$
v_1	m_1	First Stage	$M_1\ r_{e_1}$	$\frac{m_1}{M_1}$	$\frac{M_2 + M_3 \ldots + M_n}{M_1 + M_2 \ldots + M_n}$	$\frac{M_1 + M_2 + \ldots + M_n}{m_1 + M_2 + \ldots + M_n}$	$-\bar{v}_j \log_e \left(\frac{1}{r_{e_1}}\right) - \bar{g}_1 \tau_{p_1}$

$\bar{v}_j$ = mean effective exhaust velocity

τ_p = time of powered flight

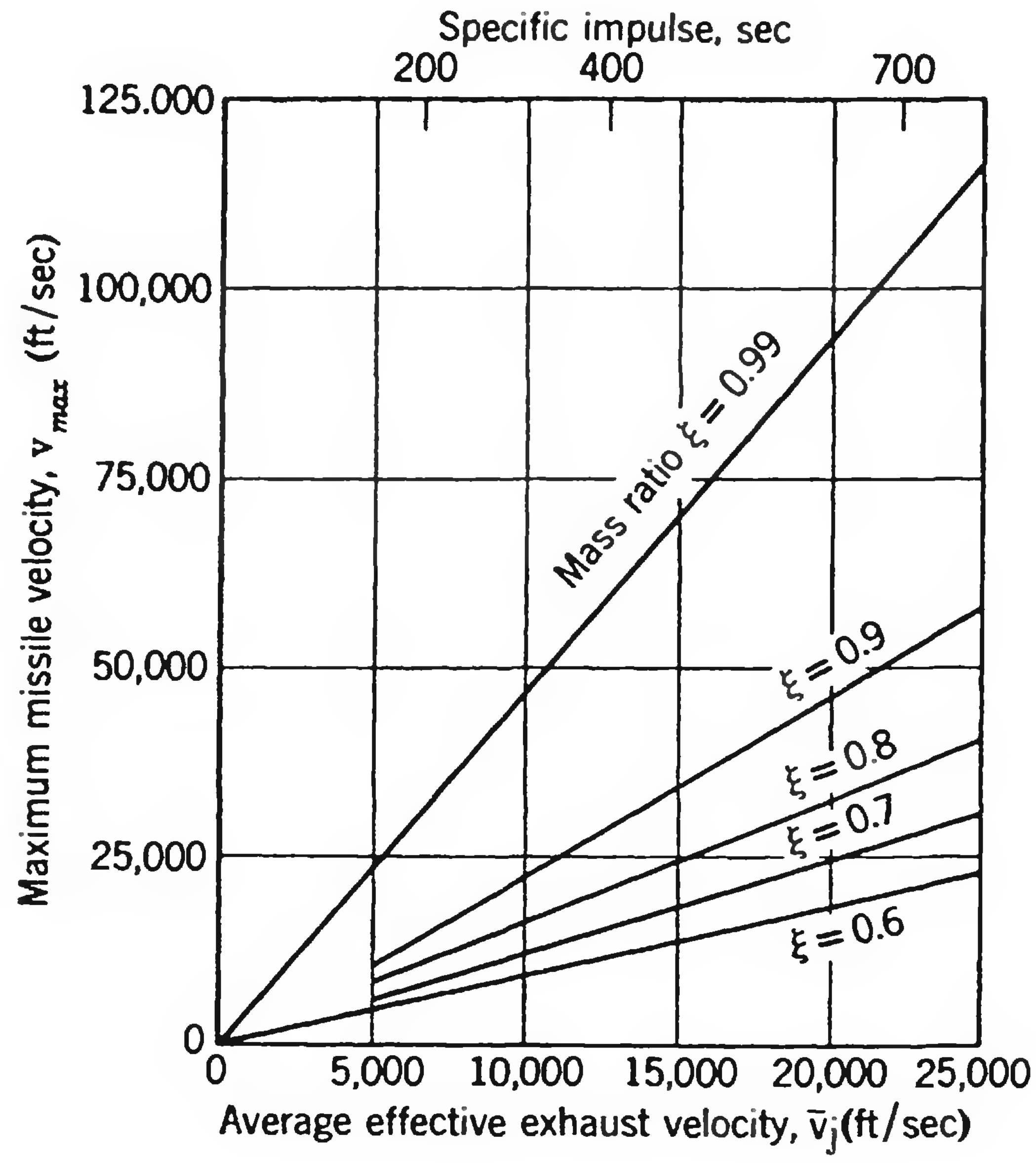
$\bar{g}$ = average value of acceleration of gravity

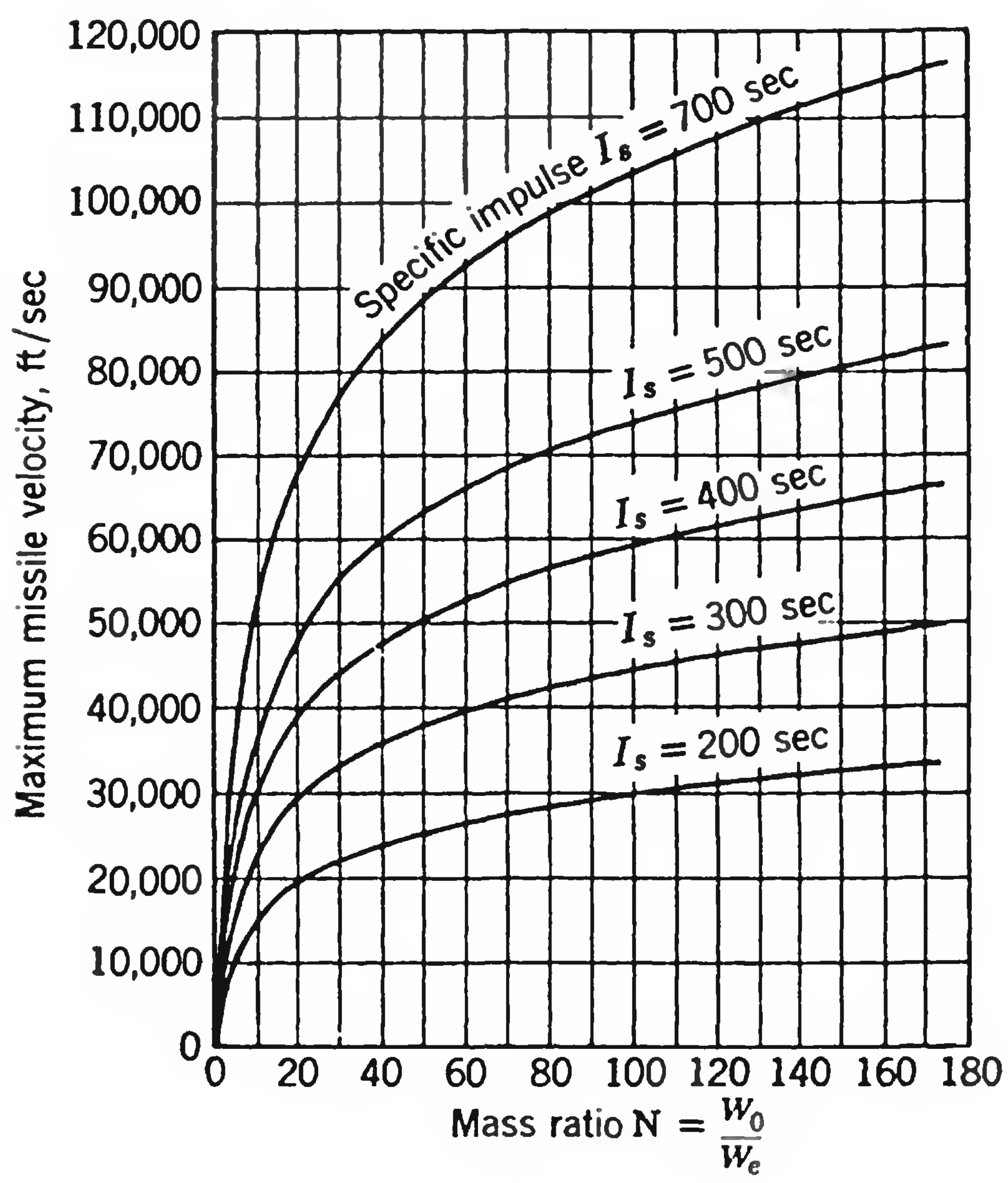
$$\epsilon = \frac{\text{empty mass of a stage}}{\text{mass of same stage loaded with propellant}}$$

$$\lambda = \frac{\text{mass of the payload}}{\text{mass of rocket at instant stage fires}}$$

$$y_k = \frac{m_{p_k}}{M_k} = \text{propellant loading ratio for kth stage}$$

FIGURE 8.2 MAXIMUM MISSILE VELOCITY IN GRAVITATIONLESS, DRAG-FREE SPACE FOR DIFFERENT MASS RATIOS AND SPECIFIC IMPULSES





$$v = \bar{v}_j \log \frac{m_o}{m_o - m_p} = \bar{c} \log N$$

where $\bar{v}_j$ = average effective exhaust vel., fps

m_o = initial launching mass, lb sec^2/ft

m_p = propellant mass, lb sec^2/ft

N = mass ratio

FIGURE 8.3 (A) MAXIMUM VELOCITY AS A FUNCTION OF LOADING DENSITY

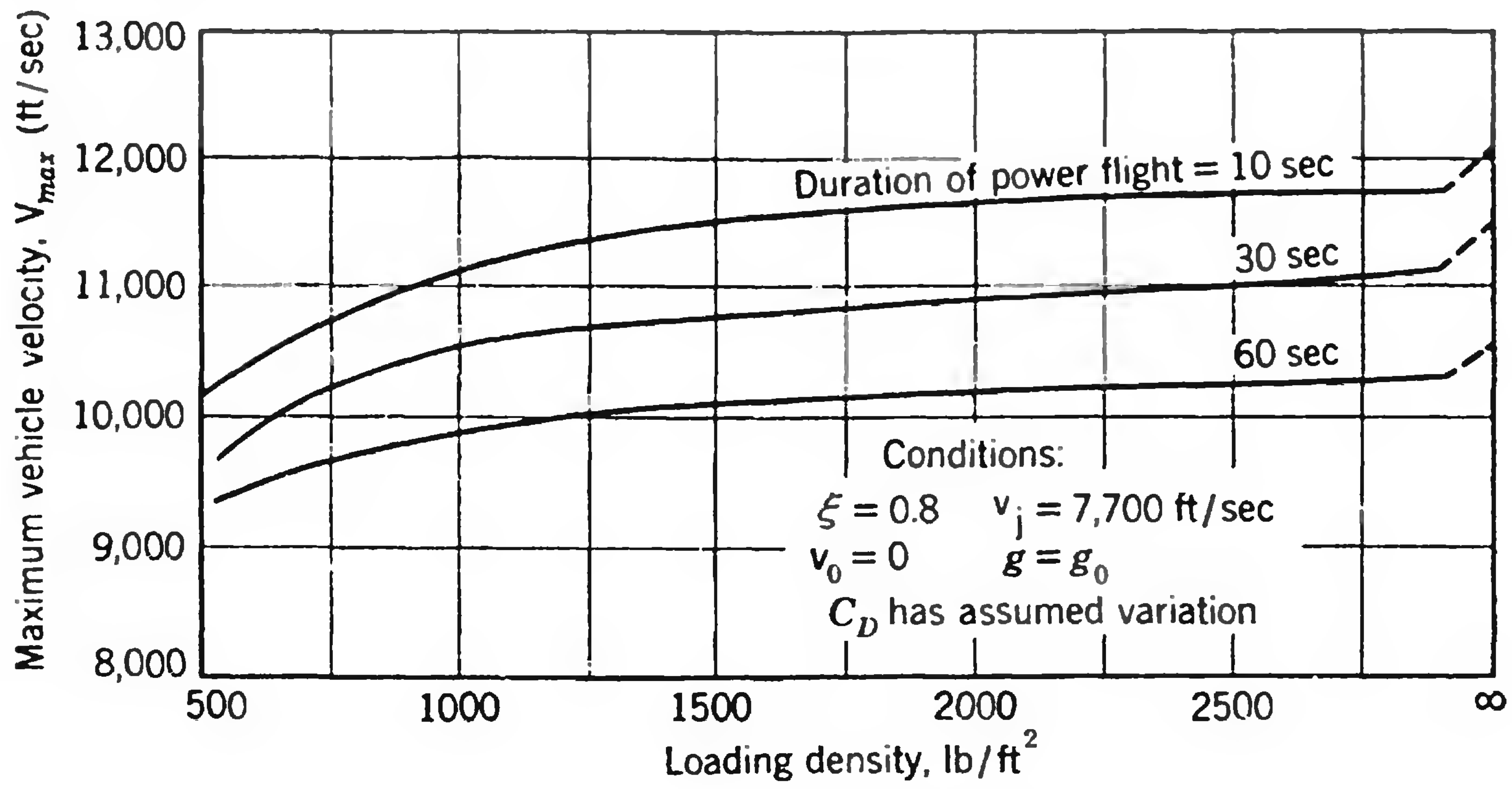


FIGURE 8.3 (B) VELOCITY AT END OF BURNING AS A FUNCTION OF MASS RATIO

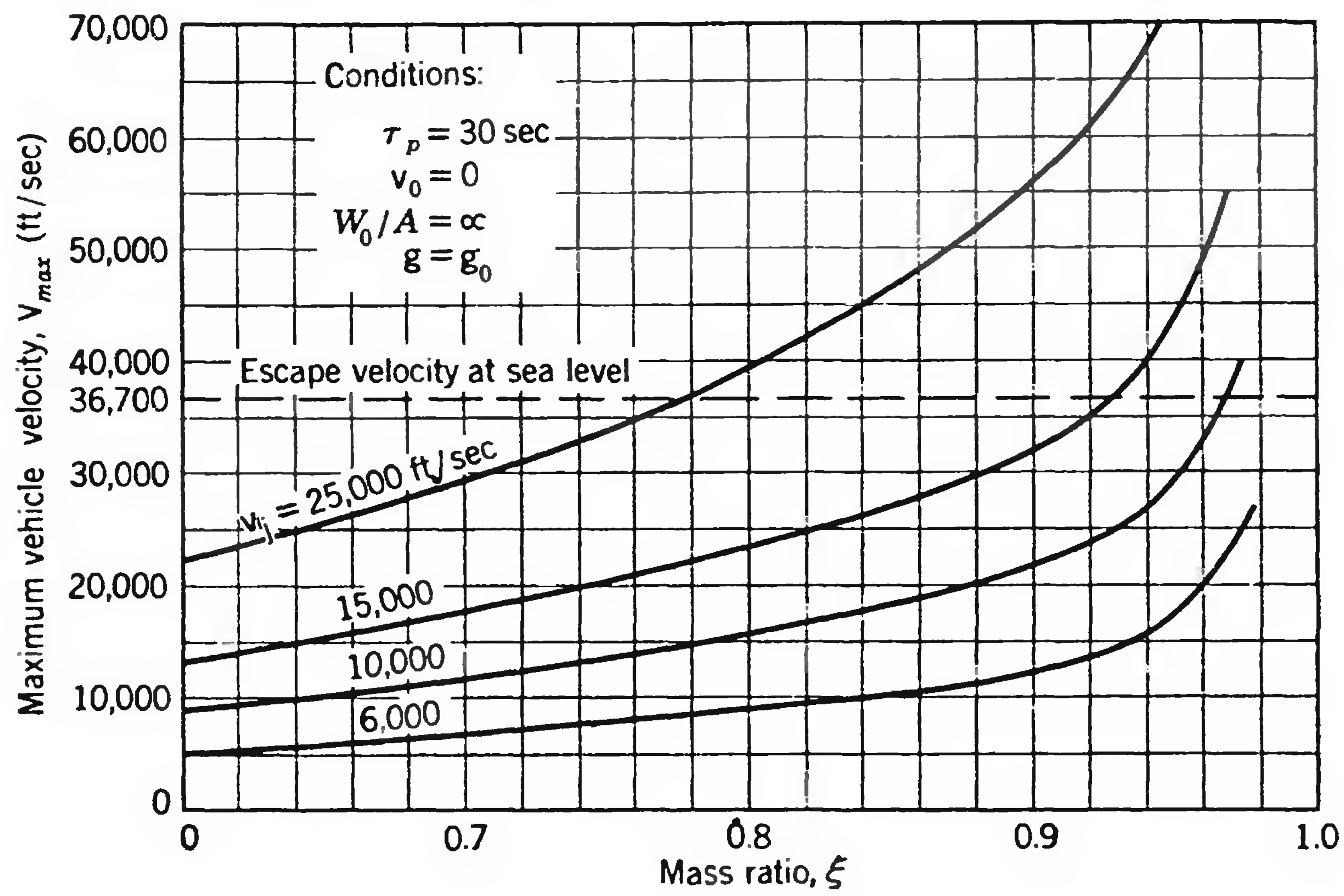
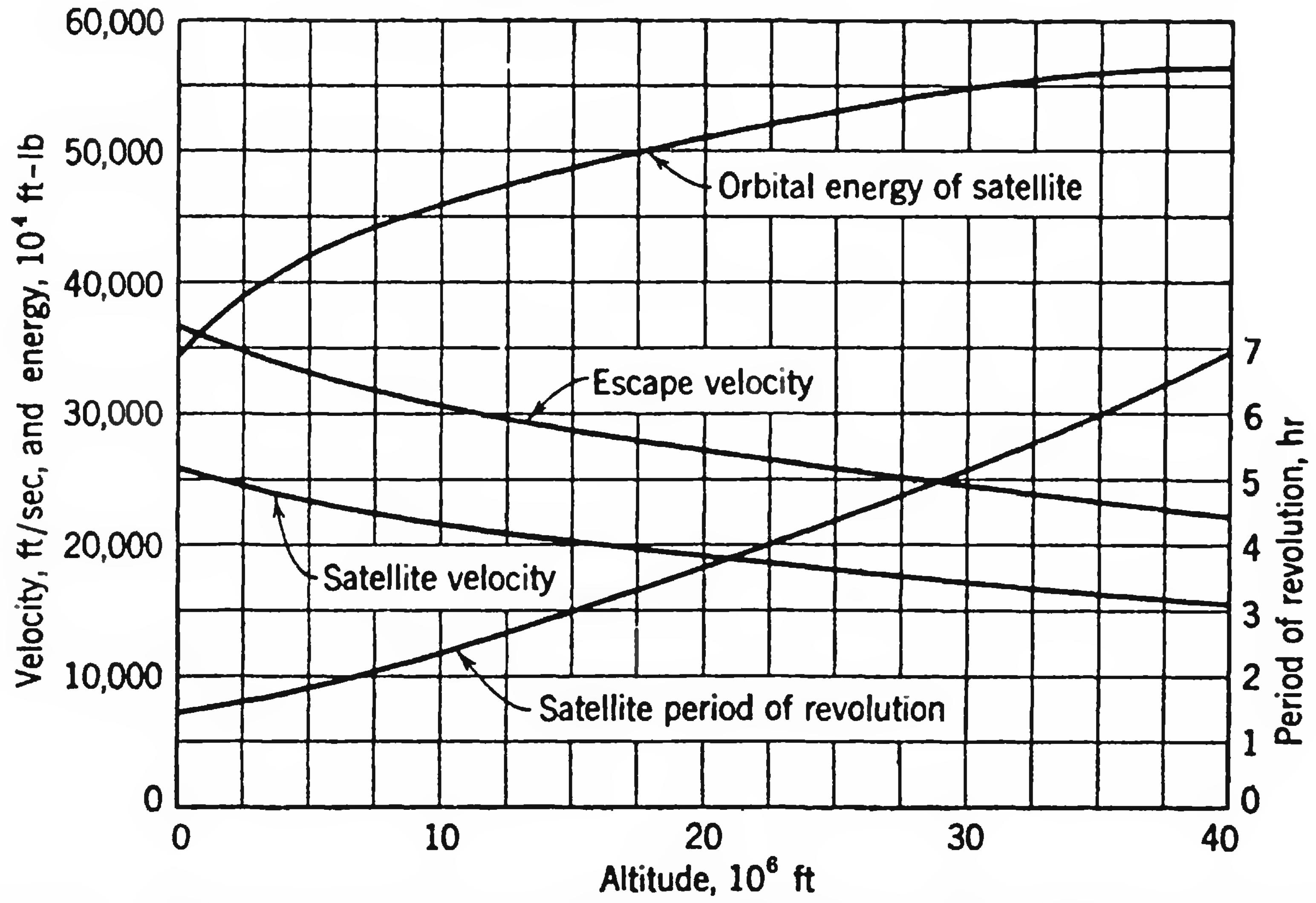


FIGURE 8.4 ORBITAL ENERGY, ORBITAL VELOCITY, PERIOD OF REVOLUTION, AND ESCAPE VELOCITY OF A SATELLITE VEHICLE AS FUNCTIONS OF ALTITUDE. A CIRCULAR SATELLITE ORBIT IS ASSUMED.



From G. P. Sutton, "Rocket Propulsion Engines," 1956, John Wiley & Sons, Inc., New York Figs. 8.2–8.4 reproduced with permission.

FIGURE 8.5 CHARACTERISTICS OF THE EARTH

1.	Mass	5.975×10^{27} grams = 13.22×10^{24} lb (avoir.)
2.	Radius	2.09029×10^{7} ft
3.	Gravity	$g = 32.172$ ft/sec^2 at 45° latitude
		$g = 32.1740$ ft/sec^2 (International Standard)

$$g = 978.0373\,(1 + 0.0052891 \sin^2 \phi - 0.0000059 \sin^2 2\phi)$$

ϕ = geographic latitude

4.	Avg. Density	5.517 g/cm^3 = 344.52 lb per cu ft
5.	Volume	38.38×10^{21} cu ft
6.	Angular Velocity	ω = 15.04106863 in./sec = 7.29211×10^{-5} rad/sec
7.	Mean Velocity (at Equator)	46500 cm/sec = 1524 ft/sec.
8.	Mean Velocity in its Orbit	18.5 miles/sec
9.	Gravitational Constant	$k = 6.673 \times 10^{-8}$ cm^2 dynes/g^2
10.	Centrifugal Force (at Equator)	$m = \dfrac{\omega^2 a}{g_e} = 0.003468 = \dfrac{1}{288.4}$

11. The shape and size of the earth, as determined by terrestrial surveys in conjunction with the observation of celestial bodies from various points on the surface, or in conjunction with measurements of the acceleration due to gravity is approximated closely by an oblate spheroid, with an equatorial radius of 6.378×10^6 meters and a polar radius of 6.357×10^6 meters.

12.	Equatorial diameter	= 7926.5 statute miles	= 6883.2 nautical miles
13	Polar diameter	= 7899.6 statute miles	= 6859.9 nautical miles
14.	Mean diameter	= 7917.5 statute miles	= 6875.5 nautical miles
15.	Difference	= 26.9 statute miles	= 23.3 nautical miles

16. Oblateness (referred to equatorial dia.) $\simeq$ 0.339%

17. Radius of sphere with same volume as the earth - r = 6371.2 km = 2.092×10^7 ft.

18. 1 degree of latitude at 40° = 69 statute miles.
    1 degree of latitude at equator = 68.7 statute miles.
    1 degree of latitude at poles = 69.41 statute miles.

19. Mean distance - Earth to Sun 92,900,000 statute miles.

20. Mean distance - Earth to Moon 238,850 statute miles.

21. Mass of the Atmosphere = 5.2×10^{18} kg = 11.49×10^{18} lb

FIGURE 8.6 (A) CORRECT VALUES FOR APPARENT GRAVITY (g')
SEA LEVEL TO THE F_2 - LAYER AT LATITUDE 45°

Height, h			Apparent Gravity, g'		Height, h		
feet	miles	km	ft/sec²	cm/sec²	feet	miles	km
0	0	0	32.196	981.32	160,000	30.303	48.769
5,000	0.947	1.524	32.180	980.85	164,040	31.068	50.000
10,000	1.894	3.048	32.165	980.38	165.000	31.250	50.293
15,000	2.841	4.572	32.149	979.91	170,000	32.197	51.817
20,000	3.788	6.096	32.134	979.44	175,000	33.144	53.341
25,000	4.735	7.620	32.118	978.97	180,000	34.091	54.865
30,000	5.682	9.144	32.103	978.50	185,000	35.038	56.389
35,000	6.629	10.668	32.088	978.03	190,000	35.985	57.913
35,332	6.692	10.769	32.086	977.98	195,000	36.932	59.437
40,000	7.576	12.192	32.072	977.55	196,848	37.282	60.000
45,000	8.523	13.716	32.057	977.10	200,000	37.879	60.961
50,000	9.470	15.240	32.042	976.64	205,000	38.826	62.485
55,000	10.417	16.764	32.026	976.15	210,000	39.773	64.009
60,000	11.364	18.288	32.011	975.70	215,000	40.720	65.553
65,000	12.311	19.812	31.996	975.24	220,000	41.667	67.057
70,000	13.258	21.336	31.980	974.75	225,000	42.614	68.581
75,000	14.205	22.860	31.965	974.29	230,000	43.561	70.105
80,000	15.152	24.384	31.950	973.84	235,000	44.508	71.629
85,000	16.098	25.098	31.934	973.35	240,000	45.455	73.153
90,000	17.045	27.432	31.919	972.89	245,000	46.402	74.677
95,000	17.992	28.956	31.904	972.43	250,000	47.348	76.201
100,000	18.939	30.480	31.889	971.98	255,000	48.295	77.725
104,986	19.884	32.000	31.874	971.50	255,902	48.466	78.000
105,000	19.886	32.004	31.873	971.50	260,000	49.242	79.249
110,000	20.883	33.528	31.858	971.03	265,000	50.189	80.773
115,000	21.780	35.052	31.843	970.57	270,000	51.136	82.297
120,000	22.727	36.576	31.828	970.12	272,306	51.573	83.000
125,000	23.674	38.100	31.813	969.66	275,000	52.083	83.821
130,000	24.621	39.624	31.797	969.17	280,000	53.030	85.345
135,000	25.568	41.148	31.782	968.72	285,000	53.977	86.869
140,000	26,515	42.673	31.767	968.26	290,000	54.924	88.393
145,000	27.462	44.197	31.752	967.80	295,000	55.871	89.917
150,000	28.409	45.721	31.737	967.34	300,000	56.818	91.441
155,000	29.356	47.245	31.722	966.89	305,000	57.765	92.965

FIGURE 8.6 (A) CORRECT VALUES FOR APPARENT GRAVITY (g')
SEA LEVEL TO THE F_2 - LAYER AT LATITUDE 45°

Apparent Gravity, g'		Height, h			Apparent Gravity, g'	
ft/sec²	cm/sec²	feet	miles	km	ft/sec²	cm/sec²
31.707	966.43	310,000	58.712	94.489	31.258	952.74
31.694	966.03	315,000	59.659	96.013	31.244	952.32
31.692	965.97	320,000	60.606	97.537	31.229	951.86
31.676	965.48	325,000	61.553	99.061	31.214	951.40
31.662	965.06	330,000	62.500	100.58	31.199	950.95
31.646	964.57	335,000	63.447	102.11	31.184	950.49
31.631	964.11	340,000	64.394	103.63	31.170	950.06
31.616	963.66	345,000	65.341	105.16	31.155	949.60
31.601	963.20	350,000	66.288	106.68	31.140	949.15
31.596	963.05	355,000	67.235	108.20	31.126	948.72
31.586	962.74	360,000	68.182	109.73	31.111	948.26
31.571	962.28	365,000	69.129	111.25	31.096	947.81
31.556	961.83	370,000	70.076	112.78	31.082	947.38
31.541	961.37	375,000	71.023	114.30	31.067	946.92
31.526	960.91	380,000	71.970	115.82	31.052	946.46
31.511	960.46	385,000	72.917	117.35	31.038	946.04
31.496	960.00	390,000	73.864	118.87	31.023	945.58
31.481	959.54	393,696	74.564	120.00	31.012	945.25
31.466	959.08	395,000	74.811	120.40	31.009	945.15
31.451	958.63	400,000	75.758	121.92	30.994	944.70
31.436	958.17	4.500×10^5	85.227	137.16	30.848	940.25
31.422	957.74	5.000×10^5	94.697	152.40	30.703	935.83
31.419	957.65	5.280×10^5	100.00	160.94	30.624	933.42
31.407	957.29	5.500×10^5	104.17	167.64	30.561	931.50
31.392	956.83	6.000×10^5	113.64	182.88	30.418	927.14
31.377	956.37	6.500×10^5	123.11	198.12	30.277	922.84
31.370	956.16	7.000×10^5	132.58	213.36	30.136	918.55
31.362	955.91	7.500×10^5	142.05	228.60	29.997	914.31
31.347	955.46	8.000×10^5	151.57	243.84	29.858	910.07
31.332	955.00	8.500×10^5	160.98	259.08	29.721	905.90
31.318	954.57	9.000×10^5	170.45	274.32	29.584	901.72
31.303	954.12	9.500×10^5	179.92	289.56	29.448	897.58
31.288	953.66	9.842×10^5	186.41	300.00	29.356	894.77
31.273	953.20					

FIGURE 8.6(B) CORRECT VALUES FOR APPARENT GRAVITY (g') ABOVE THE F_2-LAYER AT LATITUDE 45°.

Height, h			Apparent Gravity, g'		Height, h		
feet	miles	km	ft/sec	cm/sec	feet	miles	km
9.842×10^5	186.41	300	29.359*	894.87*	2.789×10^6	528.2	850
1.066×10^6	201.9	325	29.139	888.17	2.953×10^6	559.2	900
1.148×10^6	217.5	350	28.922	881.54	3.117×10^6	590.3	950
1.230×10^6	233.0	375	28.707	874.98	3.281×10^6	621.4	1000
1.312×10^6	248.5	400	28.494	868.51	3.609×10^6	683.5	1100
1.394×10^6	264.1	425	28.284	862.10	3.937×10^6	745.6	1200
1.476×10^6	279.6	450	28.076	855.76	4.265×10^6	807.8	1300
1.558×10^6	295.1	475	27.870	849.49	4.593×10^6	869.9	1400
1.640×10^6	310.7	500	27.674	843.49	4.921×10^6	932.0	1500
1.722×10^6	326.2	525	27.466	837.15	5.249×10^6	994.2	1600
1.804×10^6	341.8	550	27.267	831.09	5.577×10^6	1056	1700
1.886×10^6	357.3	575	27.070	825.08	6.562×10^6	1243	2000
1.968×10^6	372.8	600	26.908	820.15	8.202×10^6	1553	2500
2.050×10^6	388.4	625	26.682	813.27	9.842×10^6	1864	3000
2.133×10^6	403.9	650	26.492	807.47	1.148×10^7	2175	3500
2.297×10^6	435.0	700	26.119	796.10	1.312×10^7	2485	4000
2.461×10^6	466.0	750	25.754	784.97	1.476×10^7	2796	4500
2.625×10^6	497.1	800	25.396	774.07	1.640×10^7	3107	5000

*Different from Fig. 8.6 (A) due to use of different atmospheric model.

FIGURE 8.7 CHARACTERISTIC DATA FOR SEVERAL HEAVENLY BODIES*

Name	Mean Radius of Orbit, million miles	Period of Revolution	Mean Diameter, miles	Relative Mass (Earth = 1.0)
Sun	—	— days	864,100	331,950
Moon	0.23886	27.3 days	2,160	0.012
Mercury	35.96	87.97 days	3,100	0.05
Venus	67.20	224.70 days	7,600	0.81
Earth	92.90	365.256 days	7,917.5	1.00
Mars	141.6	686.98 days	4,140	0.11
Jupiter	483.3	11.86 years	86,800	318.4
Saturn	886.2	29.46 years	71,500	95.3
Uranus	1783.0	84.01 years	29,400	14.5
Neptune	2794.0	164.8 years	27,000	17.2
Pluto	3670.0	247.7 years	~3,600	?

*Data taken in part from W. E. Forsythe, Smithsonian Physical Tables, Smithsonian Institution, Washington, D. C., 1954, and in part from The American Ephemen's and Nautical Almanac, U. S. Government Printing Office, Washington, D. C., 1953.

FIGURE 8.6(B) CORRECT VALUES FOR APPARENT GRAVITY (g') ABOVE THE F_2 -LAYER AT LATITUDE 45°.

Apparent, Gravity, g'		Height, h			Apparent Gravity, g'	
ft/sec	cm/sec	feet	miles	km	ft/sec	cm/sec
25.046	763.39	1.968 x 10^7	3728	6000	8.538	260.23
24.703	752.94	2.297 x 10^7	4350	7000	7.309	222.78
24.366	742.69	2.625 x 10^7	4971	8000	6.327	192.86
24.037	732.66	2.953 x 10^7	5592	9000	5.531	168.59
23.399	713.19	3.281 x 10^7	6214	10,000	4.876	148.63
22.785	694.48	4.921 x 10^7	9320	15,000	2.862	87.23
22.195	676.51	6.562 x 10^7	12,427	20,000	1.880	57.29
21.628	659.22	8.202 x 10^7	15,534	25,000	1.328	40.49
21.082	642.58	9.842 x 10^7	18,641	30,000	0.988	30.12
20.557	626.57	1.148 x 10^8	21,748	35,000	0.764	23.28
20.051	611.15	1.312 x 10^8	24,855	40,000	0.608	18.53
18.640	568.15	1.476 x 10^8	27,961	45,000	0.495	15.10
16.599	505.94	1.640 x 10^8	31,068	50,000	0.411	12.54
14.876	453.42	1.804 x 10^8	34,175	55,000	0.347	10.58
13.408	408.67	1.968 x 10^8	37,282	60,000	0.297	9.05
12.147	370.23	2.297 x 10^8	43,496	70,000	0.224	6.83
11.055	336.97					
10.105	308.00					

FIGURE 8.7 CHARACTERISTIC DATA FOR SEVERAL HEAVENLY BODIES*

Specific Gravity	Acceleration of Gravity at Surface, ft/sec	Gravity Ratio (Relative to Earth)	Escape Velocity at Earth's Surface	
			ft/sec	
1.41	897.07	27.83	2,023,000	383
3.33	5.190	0.16	7,693	1.47
5.46	10.449	0.32	13,109	2.2
5.06	28.297	0.88	33,697	6.3
5.52	32.172	1.0	36,677	7.0
4.12	12.95	0.40	16,825	3.1
1.35	85.27	2.64	197,700	37.0
0.71	37.62	1.17	119,200	22.0
1.56	33.85	1.05	72,490	13.0
2.47	47.61	1.48	82,380	14.0
—	—	—		—

* Data taken in part from W. E. Forsythe, Smithsonian Physical Tables, Smithsonian Institution, Washington, D. C., 1954, and in part from the American Ephemen's and Nautical Almanac, U. S. Government Printing Office, Washington, D. C., 1953.

FIGURE 8.8 MAXIMUM VEHICLE VELOCITIES FOR TYPICAL INTERPLANETARY MISSIONS

MISSION	IDEAL VELOCITY* ft/sec	APPROXIMATE ACTUAL VELOCITY, ft/sec
Satellite orbit around earth (no return)	26,000 to 35,000	30,000 to 41,000
Escape from earth (no return)	36,700	42,500
Escape from moon	7,700	9,200
Earth to moon (landing on moon, no return)	44,200	53,000
Earth to Mars (no return)	57,500	66,000
Earth to Venus (no return)	73,000	85,000
Earth around moon and return to earth	74,000	83,000
Earth to moon, landing on moon and return to earth	88,000	105,000
Earth to Mars, landing on Mars, and return to earth†	112,000	130,000

*Neglects air resistance, navigational corrections and gravitational losses.
†Assumes no savings by air braking during reentry.
From G. P. Sutton, "Rocket Propulsion Elements," 1956, John Wiley & Sons, Inc., New York

FIGURE 8.9 PROBABILITY OF A METEOR HIT ON 1000 SQ. FT. OF SURFACE

MASS IN GRAMS	AVERAGE NO. HITS/HOUR	HRS. BETWEEN HITS	PROBABILITY ONE HIT/DAY	TIME TO GIVE 50% CHANCE OF NO HIT
4.0	1.8×10^{-10}	5.46×10^{9}	4.4×10^{-9}	1.57×10^{8} hrs.
0.25	2.9×10^{-9}	3.38×10^{8}	7.1×10^{-8}	9.87×10^{6}
0.0025	2.9×10^{-7}	3.38×10^{6}	7.1×10^{-6}	9.87×10^{4}
1.6×10^{-4}	4.6×10^{-6}	2.14×10^{5}	1.1×10^{-4}	6.2×10^{3}
2.5×10^{-5}	2.9×10^{-5}	3.38×10^{4}	7.1×10^{-4}	9.87×10^{2}
4.0×10^{-6}	1.8×10^{-4}	5440	.0044	157
6.3×10^{-7}	1.2×10^{-3}	846	.028	24.4
1.0×10^{-7}	.00722	138	.159	4.0
1.6×10^{-8}	.0466	21.4	.673	.62

From W. Proell and N. J. Bowman, "Handbook of Space Flight," Perastadion Press.

FIGURE 8.9 PROBABILITY OF A METEOR HIT ON 1000 SQ. FT. OF SURFACE (cont.)

MASS IN GRAMS	AVERAGE NO. HITS/HOUR	HRS. BETWEEN HITS	PROBABILITY ONE HIT/DAY	TIME TO GIVE 50% CHANCE OF NO HIT
2.5×10^{-9}	0.295	3.38	1.000	0.0987
4.0×10^{-10}	1.84	.544	1.000	.0157
6.3×10^{-11}	11.8	.0846	1.000	2.4×10^{-3}
1.0×10^{-11}	72.2	.0138	1.000	4.0×10^{-4}
1.6×10^{-12}	466.	2.14×10^{-3}	1.000	6.2×10^{-5}
2.5×10^{-13}	2950.	3.39×10^{-4}	1.000	9.8×10^{-8}

FIGURE 8.10 CUMULATIVE PROBABILITY OF METEOR HITS

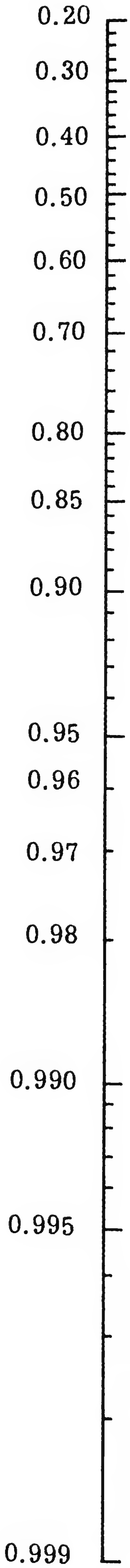
MASS IN GRAMS	CUMULATIVE AVERAGE NO. HITS/HOUR	CUMULATIVE HRS: BETWEEN HITS	CUMULATIVE PROBABILITY ONE HIT/DAY	CUMULATIVE TIME TO GIVE 50% CHANCE OF NO HIT
4.0	1.86×10^{-10}	5.36×10^{9}	4.47×10^{-9}	3.72×10^{9}
.25	4.78×10^{-9}	2.10×10^{8}	1.15×10^{-7}	1.45×10^{8}
.0025	4.9×10^{-7}	2.04×10^{6}	1.20×10^{-5}	1.4×10^{6}
1.6×10^{-4}	7.75×10^{-6}	1.29×10^{5}	1.86×10^{-4}	8.9×10^{4}
2.5×10^{-5}	4.9×10^{-5}	2.05×10^{4}	1.18×10^{-3}	1.4×10^{4}
4.0×10^{-6}	3.1×10^{-4}	3.23×10^{3}	7.42×10^{-3}	2.25×10^{3}
6.3×10^{-7}	1.96×10^{-3}	5.11×10^{2}	.046	360.
1.0×10^{-7}	.0123	81.	.256	56.
1.6×10^{-8}	.0775	13.0	.844	8.9
2.5×10^{-9}	.49	2.04	1.000	1.4
4.0×10^{-10}	3.10	.323	1.000	.225
6.3×10^{-11}	19.6	.0511	1.000	.036
1.0×10^{-11}	123.	8.1×10^{-3}	1.000	5.6×10^{-3}
1.6×10^{-12}	775.	1.3×10^{-3}	1.000	8.9×10^{-4}
2.5×10^{-13}	4900.	2.0×10^{-4}	1.000	1.4×10^{-4}

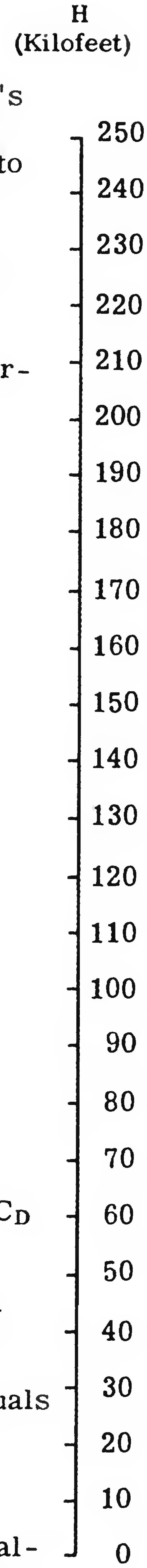
FIGURE 8.11 RADIATION FROM A BLACK BODY TO EMPTY SPACE

Temperature of Radiator °C	Energy Radiated	
	Ergs/cm²/second	Calories/cm²/second
38	5.37 x 10^5	1.29 x 10^{-2}
40	5.51 x	1.32 x
42	5.65 x	1.36 x
44	5.79 x	1.39 x
46	5.94 x	1.42 x
48	6.09 x	1.46 x
50	6.24 x	1.50 x
52	6.40 x	1.54 x
54	6.56 x	1.57 x
56	6.72 x	1.61 x
58	6.80 x	1.65 x
60	7.05 x	1.69 x
70	7.94 x	1.91 x
80	8.91 x	2.14 x
90	9.96 x	2.39 x
100	1.11 x 10^6	2.66 x
200	2.87 x	6.89 x
300	6.18 x	1.48 x 10^{-1}
400	1.18 x 10^7	2.83 x
500	2.05 x	4.92 x
600	3.33 x	7.99 x
700	5.14 x	1.23 x 10^0
800	7.60 x	1.82 x
900	1.11 x 10^8	2.66 x
1000	1.50 x	3.60 x
1500	5.66 x	1.36 x 10
2000	1.53 x 10^9	3.67 x
3000	6.57 x	1.58 x 10^2
4000	1.91 x 10^{10}	4.58 x
5000	4.43 x	1.06 x 10^3
6000	8.87 x	2.13 x
7000	1.63 x 10^{11}	3.91 x
8000	2.68 x	6.43 x
9000	4.24 x	1.02 x 10^4
10000	6.38 x	1.53 x
15000	3.12 x 10^{12}	7.49 x
20000	9.68 x	2.32 x 10^5
25000	2.34 x 10^{13}	5.62 x

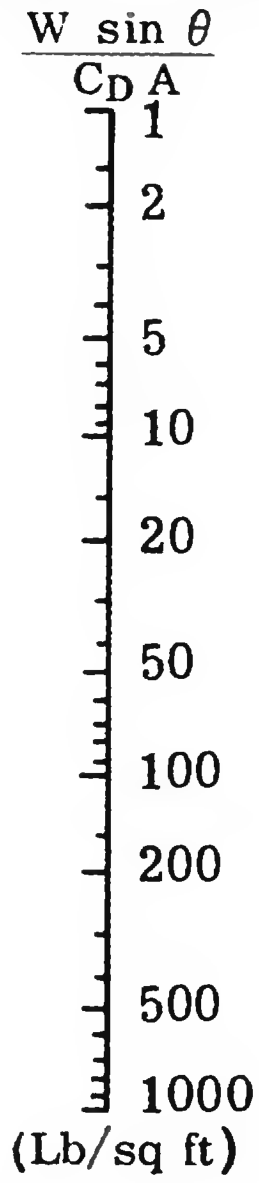
From W. Proell and N. J. Bowman, "Handbook of Space Flight," Perastadion Press.

FIGURE 8.12 ATMOSPHERIC REENTRY SLOWDOWN





In calculations relating to objects reentering the earth's atmosphere, frequently a large number of calculations must be made over a wide range of variables relating to weight and size. The accompanying nomogram for atmospheric reentry slowdown is based on exponential variation of atmospheric density, and constant value of weight-drag parameter. That these assumptions are sufficiently accurate must be determined by each designer, but if they are, then the accompanying chart permits a rapid access to velocity-altitude information.



The symbols used in the defining equation,

$$V = V_E \exp\left[-\frac{11,000\ C_D\ A\,\rho_o g}{W \sin \theta}\ \epsilon^{-H/22,000}\right], \text{ are:}$$

V	Velocity during reentry	A	Reference area for C_D
V_E	Velocity before reentry	θ	Reentry angle
W	Body weight	H	Altitude
C_D	Drag coefficient	ρ_o	Sea level air density
g	Gravitational constant		

The marker on the $\frac{V}{V_E}$ scale at approximately 0.607 (equals $\epsilon^{-1/2}$) indicates the altitude of maximum slowdown for a given value of $\frac{W \sin \theta}{C_D A}$.

Where the value of this latter parameter changes with altitude, one may determine a method of utilizing the chart for this varying value. In any case, when gravity becomes appreciable with respect to drag, the chart becomes somewhat inaccurate.

FIG. 8.13 BALLISTIC TRAJECTORY RANGES

In preliminary work relating to ballistic missile analysis, it is frequently desired to have quickly available consistent values of range, launch and reentry angle and velocity. The accompanying nomogram, or two parts, provides such information. In place of range, a range angle is given which is an angle determined by the range subtended by the ballistic portion of the trajectory divided by the distance from the center of a stationary earth to the beginning or end of the ballistic trajectory.

The larger nomogram consisting of a quadrant, semi-circle and straight line is a double alignment chart. Consistent values of velocity, launch or reentry angle and range angle are given by parallel lines, one of which intersects the range angle scale and the velocity scale at the pivot, and the other of which intersects the velocity scale and the launch angle semi-circle at one point, at least.

The equation which relates velocity, launch or reentry angle and range angle has as one form

$$\tan \eta/2 = \frac{\sin \Psi \ \cos \Psi}{2g R_e/v^2 - \cos^2 \Psi}$$

η = range angle radians (an angle determined by the range subtended by the ballistic portion of the trajectory divided by the distance from the center of a stationary earth to the beginning or end of the ballistic trajectory)

Ψ = launch angle
v = velocity, ft/sec
g = acceleration due to gravity, ft/sec^2
R_e = distance, earth's center to ballistic trajectory range extremes.

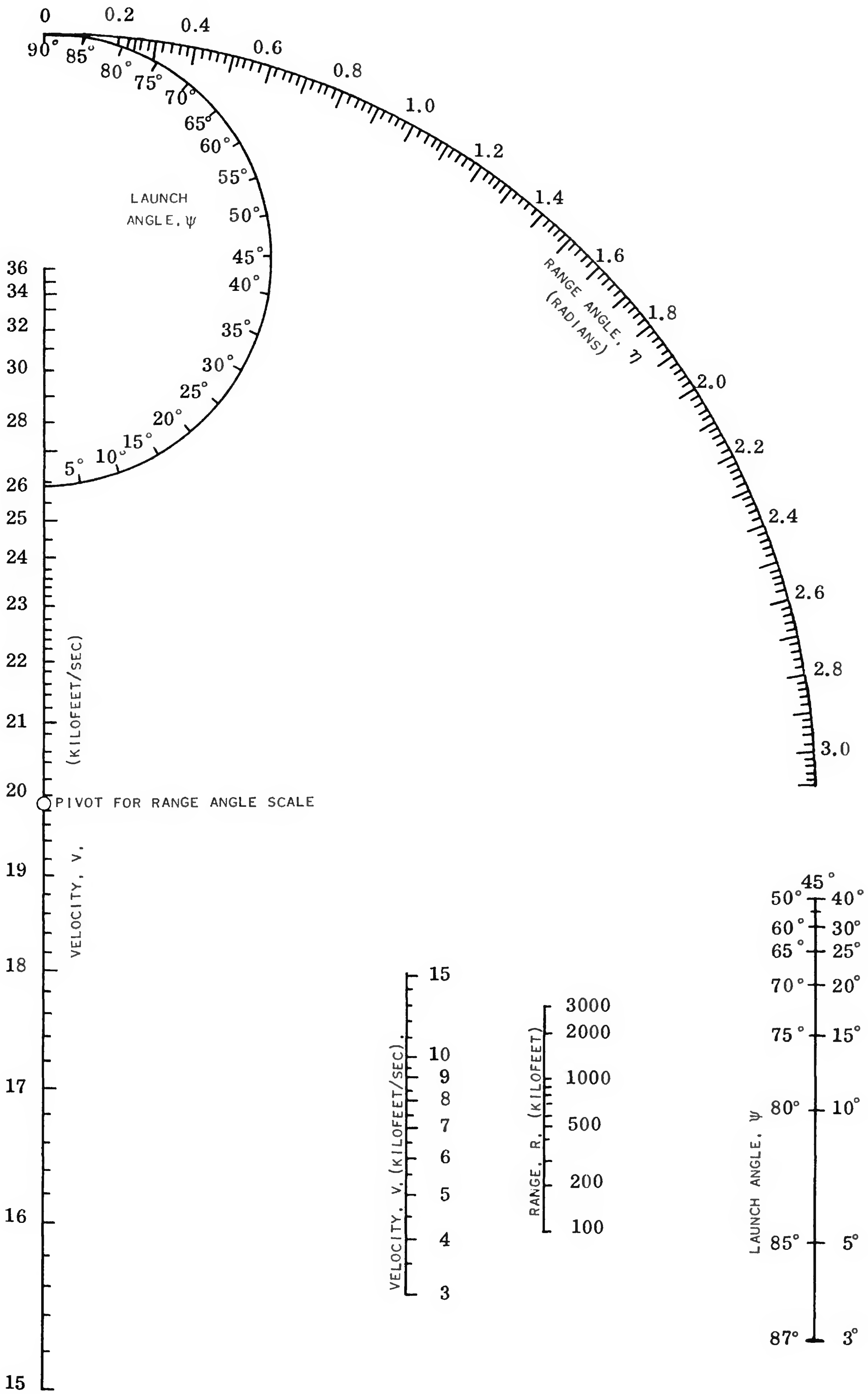
As ranges and velocities become small relative to continental dimensions, suitable "flat earth" approximations may be used to obtain consistent values of the parameters involved, and the following equation gives this relationship;

$$\text{range} = (v^2 \sin 2\Psi)/g$$

Range Angle Conversion for a Completely Ballistic Trajectory

η (radians)	Range, R (nautical miles)
0.00	0
0.15	500
0.29	1000
0.44	1500
0.58	2000
0.73	2500
0.87	3000
1.02	3500
1.16	4000
1.31	4500
1.45	5000
1.60	5500
1.75	6000

FIGURE 8.13 BALLISTIC TRAJECTORY RANGES (cont.)



SECTION 9—MISCELLANEOUS DATA

SELECTED LIST OF SPECIFICATIONS APPLICABLE TO GUIDED MISSILES

Specification No.	Title
MIL-A-8064A	Actuators and Actuating Systems; Aircraft, Electro-Mechanical, General Requirements For
MIL-A-7772A	Antenna Systems, Airborne; General Specification For The Design, Location, And Installation of
MIL-B-18B	Batteries, Dry
MIL-B-6146	Batteries; Storage Shielded, General Specification For
MIL-B-5087A	Bonding; Electrical (For Aircraft)
MIL-B-5005A	Breakdown; Provisioning Parts and Illustrated Parts For Aeronautical Articles
MIL-C-5688A	Cable Assemblies; Aircraft, Proof Testing and Pre-stretching Of
MIL-C-25038	Cable, Electric, Aircraft, High Temperature And Fire Resistant
MIL-C-17B	Cables, Radio Frequency; Coaxial, Dual Coaxial, Twin Conductor and Twin Lead
MIL-C-172B	Cases; Bases, Mounting; And Mounts, Vibration (For Use With Electronic Equipment In Aircraft)
MIL-STD-210	Climatic Extremes For Military Equipment
MIL-C-3608	Connectors, "BNC", For Radio Frequency Cables
MIL-C-5015B	Connectors, Electrical "AN" Type
MIL-C-7974	Connectors, External Power, Plug and Receptacles, And Cable Assemblies
MIL-C-71A	Connectors, "N", For Radio Frequency Cables
MIL-C-7958	Controls; Push-Pull, Flexible and Rigid
MIL-C-7413A	Couplings, Quick Disconnect, Automatic Shut-Off
MIL-C-5503B	Cylinders; Aircraft, Hydraulic Actuating
MIL-D-9310	Data For Evaluation and Development Of Guided Missile Weapons Systems
MIL-D-5825	Data; Weight and Balance Control, Guided Missiles
MIL-STD-108C	Definitions Of And Basic Requirements For Enclosures For Electric and Electronic Equipment
MIL-D-5028A	Drawings and Data Lists; Preparation of Manufacturers' (For Production Aircraft, Guided Missiles, Engines, Accessories and Other Auxiliary Equipment)
MIL-D-9281	Drawings and Drawing Indices; Preparation Of By Manufacturers (For Production Electronic Equipment)

SELECTED LIST OF SPECIFICATIONS APPLICABLE TO GUIDED MISSILES (cont.)

Specification No.	Title
MIL-STD-15A	Electrical and Electronic Symbols
MIL-E-9156	Electrical Equipment, Guided Missiles, Installation Of, General Specification For
MIL-E-1C	Electron Tubes and Crystal Rectifiers
MIL-E-4682B	Electron Tubes, Choice and Application Of
MIL-E-4158A	Electronic Equipment, Ground; General Requirements For
MIL-E-8189A	Electronic Equipment, Guided Missiles, General Specification For
MIL-E-5010A	Engines, Aircraft, Turbojet, Acceptance Test For
MIL-E-5007A	Engines, Aircraft Turbojet, General Specification For
MIL-E-50008A	Engines, Aircraft, Turbojet, Model Specification For (Outline And Instructions For Preparation)
MIL-E-5009A	Engines, Aircraft, Turbojet, Qualification Tests For
MIL-E-8222A	Engines, Ramjet, Acceptance Test For
MIL-E-8219A	Engines, Ramjet, General Specification For
MIL-E-8220A	Engines, Ramjet, Model Specifications For, Outline and Instructions For Preparation Of
MIL-E-8223A	Engines, Ramjet, Preliminary Flight Rating Test For
MIL-E-8221A	Engines, Ramjet, Qualification Tests For
MIL-E-5272A	Environmental Testing, Aeronautical and Associated Equipment, General Specification For
MIL-F-5504A	Filters, Hydraulic, Aircraft
MIL-F-7179	Finishes and Coatings; General Specification For Protection Of Aircraft
MIL-F-4960	Flight Control Subsystem, Air Weapons Systems Requirements For Preparation Of Specifications For
MIL-F-9490	Flight Control Systems, Design Installation, And Test Of, General Requirements For
MIL-F-25352	Flutter, Divergence, And Reversal In Aircraft; Prevention Of
MIL-G-008512A	Ground Support Equipment, General Requirements For
MIL-H-5166B	Handbook; Assembly, Service, and Maintenance Instructions (For Guided Missiles)
MIL-H-9210B	Handbooks; Inspection Requirements (Guided Missiles)

SELECTED LIST OF SPECIFICATIONS APPLICABLE TO GUIDED MISSILES (cont.)

Specification No.	Title
MIL-H-8031A	Handbooks; Lists Of Applicable Publications
MIL-H-6814A	Handbooks, Overhaul (Electronic, Electrical, Electro-Hydraulic, Test Equipment) Electro-Mechanical Equipments, Systems and Preparation Of
MIL-H-7985	Handbooks; Overhaul Instructions (Liquid Propellant Rocket Engines)
MIL-H-6738A	Handbooks; Overhaul Instructions With Parts Breakdown (For Relatively Simple Accessories and Equipment)
MIL-H-5440B	Hydraulic Systems; Design, Installation and Tests Of Aircraft (General Specification For)
MIL-STD-130	Identification and Marking of U.S. Military Property
MIL-I-8500A	Interchangeability and Replaceability, Physical, Of Component Parts For
MIL-I-6051A	Interference Limits and Methods of Measurements, Electrical and Electronic Installation In Airborne Weapons Systems and Associated Equipment
MIL-I-6181B	Interference Limits, Tests and Design Requirements, Aircraft, Electrical and Electronic Equipment
JAN-I-225	Interference Measurements, Radio, Methods Of, 150 Kilocycles to 20 Megacycles (For Components and Complete Assemblies)
MIL-I-7032D	Inverter, Aircraft, General Specification For
MIL-L-3890	Lines, Radio Frequency Transmission (Coaxial, Air Dielectric)
ASESA List No. 100	List of Military Specifications and Standards
MIL-STD-17	Mechanical Symbols
MIL-M-9269	Metal Construction, Aircraft and Missile Primary Structure, Requirements For
MIL-M-8555	Missiles, Guided; Design and Construction, General Specification For
MIL-M-8090A	Mobility Requirements, Ground Support Equipment, General Specification For
MIL-E-19600	General Specifications for Electronic Modules
MIL-M-7969A	Motors, Alternating Current, 400-Cycle, 115/200 Volt System, Aircraft, General Specification For
MIL-M-8609	Motors, Direct-Current, 28-Volt System, Aircraft, General Specification For

SELECTED LIST OF SPECIFICATIONS APPLICABLE TO GUIDED MISSILES (cont.)

Specification No.	Title
MIL-P-9024A	Packaging; Guided Missile Weapon Systems, Specifications and General Requirements For
MIL-P-7948	Pickup, Telemetering, General Specification For
ANC-17	Plastics For Aircraft
MIL-P-8564A	Pneumatic Components, Aeronautical, General Specification For
MIL-P-5518A	Pneumatic Systems; Design, Installation and Tests In Aircraft
MIL-P-116B	Preservation, Methods Of
MIL-Q-5923C	Quality Control Requirements, General
MIL-R-7705A	Radomes; General Specification For
MIL-R-6809	Regulator, Voltage, 30-Volt, Direct Current Generator, General Specification For
MIL-R-5519A	Regulators; Aircraft Hydraulic Pressure
MIL-R-6106B	Relays; Electric, Aircraft, General Specification For
MIL-R-5520A	Reservoirs; Hydraulic
MIL-R-11B	Resistors; Fixed, Composition (Insulated)
MIL-R-10509A	Resistors; Fixed, Film (High Stability)
MIL-R-93A	Resistors; Fixed, Wirewound (Accurate)
JAN-R-184	Resistors; Fixed, Wirewound (Low Power)
MIL-R-26B	Resistors; Fixed, Wirewound (Power Type)
MIL-STD-105A	Sampling Procedures and Tables For Inspection By Attributes
ANC-23, Part I and II	Sandwich Construction for Aircraft
MIL-S-9041A	Sandwich-Construction; Plastic Resin, Glass Fabric Base, Laminated Facings And Honeycomb Core For Aircraft Structural Applications
MIL-S-7839	Screws; Structural, Aircraft
MIL-S-4456	Shock; Variable Duration, Method and Apparatus For
MIL-S-5944	Slings; Aircraft, General Specification For
MIL-S-8048A	Specifications; Air Weapons Systems, Requirements For Preparation Of
MIL-S-8169A	Specifications; Detail, Guided Missile, Requirements For Preparation

SELECTED LIST OF SPECIFICATIONS APPLICABLE TO GUIDED MISSILES (cont.)

Specification No.	Title
MIL-S-9412	Specifications; Support Equipment Air Weapons Systems, Requirements For Preparation Of
ANC-5	Strength of Metal Aircraft Elements
MIL-S-7513A	Systems, Sets and Components, Method For Obtaining Assignment Of Nomenclature
MIL-T-5208A	Tanks; Removable, Liquid Propellant Rocket Engine, General Specification For
MIL-T-8191	Test and Checkout Equipment; Guided Missile Weapon Systems; General Specification For
MIL-T-945A	Test Equipment; For Use With Electronic Equipment, General Specification
MIL-T-5522B	Test Procedure For Aircraft Hydraulic and Pneumatic Systems, General
MIL-T-9107	Test Reports, Preparation Of
MIL-T-25310	Trainer, Guided Missile Guidance Procedure, General Specification For
MIL-T-4860A	Trainers, Operational Procedure, General Requirements For
MIL-T-4857	Training Equipment, Weapons Systems, Specifications and Engineering Test Outlines, Instructions and Requirements For Preparation Of
MIL-T-19500A	General Specification for Transistors
ANC-12	Vibration and Flutter Prevention Handbook
MIL-W-287A	Wave Guide Assemblies, Flexible, General Specification For
MIL-W-85C	Waveguides, Rigid, Rectangular
MIL-W-9411	Weapons Systems; Air, General Specification For
MIL-W-8160	Wiring, Guided Missile, Installation Of
MIL-S-8048	Specifications; Air Weapons Systems, Requirements for Preparation of
MIL-S-8169	Specifications; Detail, Guided Missile, Requirements for Preparation of
MIL-S-6644	Specifications; Research and Development, Contractor Prepared

SELECTED LIST OF SPECIFICATIONS APPLICABLE TO GROUND SUPPORT EQUIPMENT

Specification No.	Title
MIL-C-17B	Cables, Radio Frequency; Coaxial, Dual Coaxial, Twin Conductor, and Twin Lead
JAN-S-23	Switches, Toggle (For Electronic and Communications Use)
MIL-P-116B	Preservation, Methods of
MIL-T-704B	Treatment and Painting of Materials
MIL-T-945A	Test Equipment, For Use With Electronic Equipment; General Specification For
MIL-C-3608	Connectors, "BNC", For Radio Frequency Cables
MIL-C-3650	Connectors, "LC", For Radio Frequency Cables
MIL-C-3767	Connectors (Electrical, Power, Bladed Type)
MIL-D-3926	Knobs, Control (For Use With Electronic, Communication and Allied Equipment)
MIL-E-4158A(USAF)	Electronic Equipment, Ground; General Requirements for
MIL-M-4803 (USAF)	Motor Generator, 400 cycle Precise Output, General Requirements for
MIL-C-5015B	Connectors, Electrical, "AN" Type
MIL-W-5086	Wire, Electrical, 600-Volt, Copper, Aircraft
MIL-B-5087 (ASG)	Bonding, Electrical (For Aircraft)
MIL-C-5424	Cable, Steel (Corrosion-Resisting), Flexible, Preformed (For Aeronautical Use)
MIL-H-5440B	Hydraulic Systems; Design, Installation and Tests of, Aircraft (General Specification For)
MIL-C-5502A	Couplings; Aircraft Hydraulic, Self Sealing
MIL-F-5509A	Fittings; Fluid Connection
MIL-H-5511A	Hose, Aircraft, Hydraulic, Pneumatic, Fuel and Oil Resistant
MIL-H-5512B (ASG)	Hose Assemblies; Aircraft Hydraulic and Pneumatic, High Pressure
MIL-P-5518A	Pneumatic Systems; Design, Installation and Tests in Aircraft
MIL-C-5756B (ASG)	Cable and Wire, Power, Electric, Portable
MIL-C-5778A	Covers, Aircraft Components

SELECTED LIST OF SPECIFICATIONS APPLICABLE TO GROUND SUPPORT EQUIPMENT (cont.)

Specification No.	Title
MIL-P-5902A (USAF)	Purging Gas Systems, Aircraft Fuel Tank, Internal and External
MIL-S-5944 (USAF)	Slings, Aircraft, General Specification for
MIL-C-6021B (ASG)	Castings, Classification and Inspection of (For Aeronautical Applications)
MIL-I-6051A (USAF)	Interference Limits and Methods of Measurement, Electrical and Electronic Installation in Airborne Weapon Systems and Associated Equipment
MIL-I-6181B	Interference Limits, Test and Design Requirements, Aircraft Electrical and Electronic Equipment
MIL-P-6457A (USAF)	Power Supply, Metallic Rectifier Type, General Specification for
MIL-S-6743	Switches; Pushbutton and Limit
MIL-S-6744	Switch Assemblies and Actuators, Pushbutton and Limit
MIL-T-6845	Tubing; Steel, Corrosion-Resisting Aircraft, Hydraulic System
MIL-S-6872A	Soldering Process, General Specification For
MIL-L-7961A	Light, Indicator, Press to Test (with Information Notice 1 dated 19 October 1955)
MIL-M-8090 (ASG)	Mobility Requirements, Ground Support Equipment; General Specification for
MIL-E-8189A (ASG)	Electronic Equipment, Guided Missile, General Specification for
MIL-T-8191 (USAF)	Test and Checkout Equipment; Guided Missile Weapon Systems, General Specification for
MIL-A-8421 (USAF)	Air Transportability Requirements, Ground Support Equipment; General Specification For
MIL-I-8500A (ASG)	Interchangeability and Replaceability, Physical, of Component Parts for Aircraft (Including Guided Missiles)
MIL-T-8504 (ASG)	Tubing, Steel, Corrosion-Resistant (18-8), Annealed, Aircraft Hydraulic System
MIL-P-8564A (ASG)	Pneumatic Components, Aeronautical; General Specification for
MIL-P-9024A (USAF)	Packaging; Guided Missile Weapon Systems Specifications and General Design Requirements for
MIL-M-10304A	Meters, Electrical Indicating, Panel Type, Ruggedized

SELECTED LIST OF SPECIFICATIONS APPLICABLE TO GROUND SUPPORT EQUIPMENT (cont.)

Specification No.	Title
MIL-M-16034A	Meter, Electrical Indicating (Switchboard and Portable Types)
MIL-G-008512A (USAF)	Ground Support Equipment, General Requirements for
MIL-P-1755C	Preparation for Delivery of Electronic Equipment; Accessories, Auxiliary Equipment and Associated Repair (Maintenance) Parts
ANA Bulletin 143d	Specifications and Standards, Use Of
ASESA List 100	List of Military Specifications and Associated Publications
TO 11W - 1 - 2	Ordnance Safety Manual
MIL-STD-130	Identification Marking of U.S. Military Property
MIL-STD-129A	Marking for Shipment or Storage (Change Notice 1 dated 18 January 1955)
ARDCM 80 - 5	Handbook of Instructions for Ground Equipment Designers

REFERENCE LIST FOR ANALYSES REQUIRED FOR MISSILE DESIGN

The following Tables provide a reference to the type and scope of analyses required to design and document the design of a missile.

Design techniques, applicable equations, required emphasis, limitations and boundary conditions are not included. Reference should be made to the Series "Principles of Guided Missile Design" for detail approaches and to literature relating to each discipline.

AERODYNAMIC AND PROPULSION ANALYSIS

Three main divisions are required in this analysis effort:

I. Aerodynamic Data - Stability and control, roll, lift, moment drag and trim drag characteristics.

II. Propulsion Data - Thrust, fuel consumption, air requirements, and internal flow characteristics.

III. Performance Analysis - Estimates of boost, mid-course and terminal phase flight characteristics; separation or staging behavior.

AERODYNAMIC AND PROPULSION ANALYSIS (cont.)

I - AERODYNAMIC DATA

A. SUMMARY

Directional and lateral stability and control, roll, and drag characteristics of missile and/or missile-booster combination determined from wind tunnel test data and appropriate theoretical analyses.

B. DIRECTIONAL STABILITY AND CONTROL

Determined from wind tunnel data. Force and moment data, wing normal-force and hinge moments. M varied from below to above design flight Mach No. of missile. Minor differences between wind tunnel model and actual configuration should produce little or no effect on results, but care should be exercised in judging significance of the differences.

(1) Non-Linear Stability and Control

a. Non-Linearites in stability curve, variation with M.
b. Effect of downwash at tail on linearites.
c. Trim conditions of normal force and angle of attack as function of wing incidence in pitch and combined planes; initial c.g. conditions.
d. Aerodynamic gain in maneuverability in combined plane over pitch plane; analysis of characteristics.
e. Determination of critical maneuvering altitude.

(2) Linearized Stability and Control Derivatives

a. Effect of M.
b. Effect of maneuvering load factor.
c. Effect of roll angle.
d. Combined versus pitch plane.
e. Static normal force and pitching moment coefficients over range of stability curves.
f. Steady state or trim angle of attack versus wing incidence angle.
g. Variation of angle of attack-wing incidence ratio with M in pitch and combined planes.
h. Steady-state maneuverability, variation with M.
i. Linear range of aerodynamic characteristics versus flight condition.
j. Dynamic stability condition; variation with control derivative.
k. Conditions of minimum stability.
l. Stability versus wing incidence and M; overshoot.
m. Trim condition of zero aerodynamic stability.

(3) Linearized Stability and Control Coefficients

a. Missile equations of motion.
b. Effect of M, altitude, and c.g. on stability coefficients.
c. Critical altitudes of stability.

(4) Wing Characteristics

a. Normal force and hinge moment characteristics as function of angle of attack, wing incidence, roll angle, and M.

b. Effect of body upwash, wing-wing, wing-body, and wing-yaw interference.
c. Dissimilar force conditions on upper and lower wings.
d. Effect of body presence, angle of attack variation, interference and yaw effects on wing hinge moment characteristics.
e. Variation with M.

(5) Tail Efficiency and Downwash-Due-To-Incidence

Variation with M, angle of attack, wing incidence.

(6) Aeroelastic Effects

a. Body bending due to inertia forces and airloads.
b. Effect on lift and moment.
c. Relative importance of body, wing, and tail flexibility.
d. Normal force and pitching moment in terms of body, wing, body-wing, and tail loads.
e. Body angular deflection in terms of air and inertia loads.
f. Effect of flight temperature condition.
g. Development of static aeroelastic stability derivatives.
h. Determination of structural deflection constants.
i. Static aeroelastic effect on rigid-body-derived aerodynamic characteristics:

  1. Effect on stability derivatives.
  2. Effect on control derivatives.

j. Effect of M, altitude, and c.g.
k. Effect on critical maneuvering altitude.
l. Point of directional control reversal.
m. Effect on wing hinge moments.

(7) Airframe Dynamic Characteristics

a. Natural frequency and damping ratio versus M and altitude (based on directional stability equations of motion and aeroelastic stability coefficients).
b. Effect of fuel/propellant sloshing.
c. Effect of bending on control system/guidance.
d. Variation of c.g. with time (function of propellant consumption).

C. ROLL CHARACTERISTICS

(1) Induced Rolling Moments

a. Effects of combined pitch and yaw due to tip effect, sweepback, downwash, root effect, bodyblanketing, and lifting surface interference. Nature and magnitude of rolling moments determined by wind tunnel tests.
b. Variation with M, angle of attack, wing incidence, and roll angle.
c. Conditions of maximum induced rolling moments.

d. Effect of differential wing deflection on longitudinal stability and control characteristics.
e. Conditions of maximum induced rolling moment; effects of maximum angle of attack, trim plus overshoot, and design load factor limits on maneuvering.
f. Effect of type of maneuver and missile-plus-control-system dynamics.

(2) Roll-Control-Effectiveness

a. Wind tunnel tests of overall effectiveness; effect of tail; wing and tail interactions; lag of downwash effect on dynamic analysis of roll-control system.
b. Effect of tail-off, tail-on, wing incidence, and differential deflection.
c. Variation of derivative with M and wing incidence.
d. Wing-tail interference effects.
e. Tail contribution due to wing downwash.
f. Equation of motion of missile in roll.
g. Variation of coefficients with altitude.
h. Zero roll-control-effectiveness condition.
i. Characteristics of gimbal engine on jet vane for roll control.

(3) Roll Damping

a. Theoretical determination of characteristics, effect of body, wing interference, contribution of tail, effects of trailing edge separation.
b. Variation with M.
c. Damping-in-roll sea-level coefficients.

D. DRAG CHARACTERISTICS

(1) Zero-lift Drag

a. Theoretical estimates, effect of wing sweepback, effect of aspect ratio, body wave drag, corroboration with wind tunnel data.
b. Wave drag of shrouds, boattails, etc.
c. Antenna and static probe drag (by wind tunnel test).
d. Skin-friction drag at representative altitudes.
e. Variation with M of wave and friction-drag coefficients of wings and fins and body drag coefficient.
f. Total zero-lift drag coefficient for powered and coasting flight.
g. Cold flow internal drag versus M.
h. Total head-loss through combustor with cold flow and M at combustor inlet under these conditions.

(2) Drag-Due-To-Lift

a. Single and combined plane effects.
b. Variation with angle of attack and wing incidence.
c. Validity at various altitudes and maneuvering load factors.
d. Variation of drag-due-to-lift coefficient factors with M.
e. Variation of drag-due-to-lift parameter with M.

f. Maximum lift-drag ratio for trim conditions.
g. Variation of maximum lift-drag ratio with M, altitude, and c.g. for engine-burning and coasting conditions.
h. Variation of load factor with altitude for maximum lift-drag ratio.

(3) Aeroelastic Effects on Drag

a. Effect on drag-due-to-lift of change in trim due to body, wing, and tail flexibility under load.
b. Variation of drag-due-to-lift parameter with M with aeroelastic effects taken into account.
c. Comparison of rigid-body and aeroelastic total drag coefficients as a function of load factor and altitude.

E. MISSILE-PLUS-BOOSTER STABILITY

(1) Low Angle of Attack Characteristics

a. Non-linearity of subsonic normal force and pitching moment as a function of angle of attack.
b. Fin efficiency as function of angle of attack.
c. Variation of normal force and pitching moment characteristics with M.
e. Component center of pressure location versus M.
f. Missile tail and booster fin efficiency versus M at zero angle of attack.
g. Complete configuration normal force and moment derivatives versus M at zero angle of attack.
h. Effect of wing torsional wind-up due to hinge moments.
i. Wing panel hinge moment characteristics versus M.
j. Pitch-damping and lag-of-downwash dynamic stability derivatives versus M.
k. Jet vane or engine swiveling efficiency as a function of angle of attack.

(2) High Angle of Attack Characteristics

Pitching moment and Normal Force Coefficients versus angle of attack at low subsonic speeds (cross-wind at launch condition).

(3) Surface Misalignment Effects

a. Effects of wing and booster fin incidence and differential deflection on pitching and rolling moments.
b. Effect of wing downwash on booster fin due to wing incidence.
c. Variation of rolling moment derivatives due to wing and fin surface misalignments with M.
d. Variation of damping in roll derivatives with M.

F. MISSILE PLUS BOOSTER DRAG CHARACTERISTICS

(1) Zero-lift drag variation with M of missile-booster components.

(2) Inlet drag, handling lug and launching shoe drag, base drag, skin-friction drag, and afterbody-shroud drag characteristics versus M.

(3) Zero-lift drag variation with M of missile-booster profile.

II - PROPULSION DATA

A. SUMMARY

Performance characteristics of engine (turbojet, ramjet, rocket) and auxiliary power supply system (e.g., turbine air intake, pumps and turbines, turbine-air discharge louvers, etc.). Data based on wind tunnel tests, free-jet tests, direct-connection combustor tests, static test firings, etc. Test data supplemented by appropriate theoretical analyses (flight phase only.)

B. OVER-ALL JET ENGINE PERFORMANCE (Turbojet, Ramjet)

(1) Determined by analyses which combine diffuser performance with combustor and exit nozzle performance. Diffuser performance obtained from wind tunnel and free jet tests; combustor and exit nozzle data obtained from direct-connect tests. Analysis covering each of the 3 atmosphere conditions, Polar Day, Tropical Day, and NACA Standard Day (Nominal Day).

(2) Variation of temperature-ratio parameter with M at various altitudes for zero angle of attack.

(3) Low flight M; limitations due to lean-limit combustor blow-out.

(4) Effect of low angles of attack on engine performance.

(5) Comparison of Jet Thrust with Missile Drag

a. Effect of thrust-drag relationship versus altitude, day, velocity, and flight path elevation angles.
b. Thrust coefficients versus angle of attack.

(6) Effect on Performance of Manufacturing Tolerances

a. Quality control burner tests of production articles.
b. Theoretical determination of effect on performance of change in air-flow rates at worst combination of tolerances.

(7) Thrust Misalignment Due To Airframe Assembly Tolerances

(8) Thrust Misalignment Due To Aeroelastic Body Bending

(9) Effect of Experimental Accuracy on Predicted Performance

C. DIFFUSER PERFORMANCE AND INLET STABILITY

Comparison of flight Reynolds No. with Diffuser Test Reynolds No.

(1) Diffuser Total-Pressure Recovery Characteristics

a. Variation with angle of attack at various M.
b. Variation with M of free-stream-tube capture area.

AERODYNAMIC AND PROPULSION ANALYSIS (cont.)

(2) Theoretical Maximum Diffuser-Inlet-Force Coefficients

Variation with angle of attack and M.

(3) Diffuser-Inlet-Force Coefficients for Subcritical Flow Conditions

a. Variation with capture-area ratio and M at angles of attack.
b. Equations for prediction of consistant variation of inlet-force coefficient with angle of attack.
c. Variation of supercritical cowling drag coefficient with M.

(4) Diffuser-Inlet Stability Characteristics

a. Effect of pressure oscillations on engine performance.
b. Diffuser-inlet stability characteristics under cold-flow conditions.
c. Pressure oscillations resulting from diffuser-inlet flow instability, combustion process and fuel-injection system oscillations, and engine element coupling (surge).
d. Effects of heat addition on flow oscillations.

D. COMBUSTOR PERFORMANCE AND COMBUSTOR STABILITY

(1) Combustion Efficiency

Variation with over-all equivalence ratio at various inlet total temperatures and air-weight flows.

(2) Combustor Drag

Uni-dimensional total-pressure recovery across combustor for corresponding values of thrust parameter and diffuser-exit M.

(3) Combustion Stability

Regions of stable operation and no operation as a function of inlet-air-weight flow and over-all equivalence ratio at combuster lean limit operation.

(4) Exit Nozzle Effectiveness

a. Effect of pressure ratio across divergent portion.
b. M region of constant effectiveness.
c. Deviation of actual from theoretical exit-stream thrust.

(5) Ignition Delay

a. Comparison of effectiveness of flare and spark ignition.
b. Effect of pilot and over-all equivalence ratios.
c. Lean and rich limits of combustor ignition.

E. AUXILIARY POWER EQUIPMENT (For Units Driven by Turbines Powered From Duct Air)

(1) Diffuser Pressure Recovery at Auxiliary Power Air-Scoop Inlet

AERODYNAMIC AND PROPULSION ANALYSIS (cont.)

a. Variation of center of diffuser duct pressure recovery with angle of attack and M.
b. Comparison of center of diffuser duct total pressure recovery during normal flight conditions with specification diffuser total pressure recovery.

(2) Pressure Recovery of Turbine Air Intake Ducts

a. Effect of variation of air-flow rate through opposing duct.
b. Uniformity of velocity distribution around periphery of air scoop exit.
c. Operating points of air intake ducts as function of duct inlet M and turbine throttle position.

(3) Turbine Exhaust-Louver Area

a. Total exhaust-louver area necessary to satisfy air horsepower requirements under varying flight conditions.
b. Effect of exhaust-louver area on available air horsepower.

(4) Air Horsepower Available to Hydraulic and Fuel Pump Turbines

Effect of air-flow rate, turbine-inlet total temperature and total pressure, turbine-exhaust compartment pressure, flight M, altitude, diffuser pressure recovery, duct pressure recovery, and position of turbine throttle plate (if any).

III - PERFORMANCE ANALYSIS

A. SUMMARY

Estimated performance of missile plus booster and missile alone for boost, mid-course and terminal phases of flight respectively. Mechanics of missile-booster separation or staging. Mid-course flight calculations aimed at development of optimum launcher angle, guidance program, general "firing doctrine", optimized missile design speed, fuel metering function for best logitudinal acceleration and maximum range, determination of set of "standard" trajectories, and effects of winds, drag changes, weather changes, etc.

B. BOOST PHASE TRAJECTORY

Effects of adverse misalignments, surface winds, missile-booster offset, launching angle, tilt angle, etc.

C. SEPARATION OR STAGING CHARACTERISTICS

(1) Derivation of missile and booster equations of motion for the several phases of separation; determination of time history of forces and moments.

(2) Effects of angle of attack, lift, and aerodynamic moments on "jacknifing" tendency.

(3) Comparisons of "jacknifing" moment with restoring moment as functions of misalignments, winds, launch angle, etc.

(4) Determination of time for beginning of separation or staging.

AERODYNAMIC AND PROPULSION ANALYSIS (cont.)

(5) Time of separation and time for beginning of "jacknifing"

(6) Time history of displacement between missile and booster immediately following inception of separation or staging

(7) Effects of missile-booster joint friction, pinching due to out of roundness, etc.

D. POST-SEPARATION STAGING ACCELERATION

(1) Effect of initial missile flight speed after separation or staging on radar tracking

(2) Marginal initial flight speeds for successful flight

E. MID-COURSE TRAJECTORIES

(1) Tracking-Beam-Rider Trajectories

a. Variation of initial-target altitude.
b. Trace of missile in space.
c. Initial-target range and altitude.
d. Loci of collision points.
e. Missile flight time, M, maneuvering load factor, crossing angle, rigid body angles of attack and wing incidence.
f. Engine-operating conditions, thrust coefficients, engine-airflow ratio, propellant consumption.

(2) Programmed-Beam-Rider Trajectories

a. Equations for beam programs.
b. Missile time of flight, flight M, maneuvering load factors, missile crossing angles, rigid body trim angles of attack and incidence, engine operating thrust coefficients, airflow ratio, and percent of total fuel consumed as function of target altitude.
c. Effects of initial-flight speed, initial-target range, and initial guidance beam elevation angle on final missile range.

(3) Guidance-Beam Jitter

a. Effect of jitter on required lift and drag-due-to-lift.
b. Effect on final missile range of various jitter amplitudes.
c. Trim angles of attack and incidence required for programmed beam rider trajectory with several degrees of jitter.
d. Effect of body-bending aeroelasticity on tolerable jitter amplitude.

(4) Winds and Weather

a. Effect of wind on time of arrival and performance.
b. Effect of weather (temperature variations with altitude) on over-all propellant consumption and missile final range.

FLUTTER ANALYSIS

Part I - Theoretical Studies

Part II - Ground Vibration Tests

I - ANALYSIS BASED ON THEORETICAL DESIGN DATA

A. SUMMARY

Theoretical evaluation of mass and stiffness characteristics of wing, fin, jet vane, movable booster fin system, etc. Consideration of effect of body flexibility, lifting surface root flexibility, and aerodynamic compressibility.

B. WING

(1) Root Flexibility

Locked and unlocked conditions: effect of root torsional flexibility: effect of wing structural rigidity and over-all stiffness variations.

(2) Static Balance

(3) Wing-Body Motion Studies

a. Body with booster-wings fixed.
b. Body with booster.
c. Body without booster.

(4) Mach Number Studies

a. Effects of compressibility.
b. Binary wing bending-torsion studies.
c. Wing motion studies.

(5) Servo-Control Studies

a. Control system interaction.

C. MISSILE FIN

Effects of temperature, M, and altitude

D. BOOSTER FIN

(1) Binary bending-torsion studies

(2) Ternary studies to determine effect of root-torsional flexibility

E. PREDICTED MARGINS OF SAFETY AGAINST FLUTTER

II - GROUND VIBRATION TESTS

A. SUMMARY

Measured vibration modes for missile and missile-booster combination, with and without aerodynamic surfaces. Correlation of measured data with results of theoretical analysis.

FLUTTER ANALYSIS (cont.)

B. FREE-FREE MODES

First, second and third free-free bending and first free-free torsion modes of missile and missile-booster without aerodynamic surfaces.

C. AERODYNAMIC SURFACE CANTILEVER MODES

(1) Wing

a. Fundamental bending and torsion modes with actuator operative and wings unlocked, actuator replaced by equivalent stiffness link and wings unlocked, and with wings locked.

(2) Missile Fin

Effect of Slop in fittings.

(3) Booster Fin

a. Effect of body coupling.
b. Effect of slop in fittings.

D. NORMAL MODES

(1) Missile Plus Booster with Propellant

(2) Missile Plus Booster without Propellant

(3) Missile only with propellant

(4) Missile only without propellant

E. STRUCTURAL DAMPING

Decay curves of body free-free bending and torsion modes.

F. CORRELATION OF TEST RESULTS WITH THEORETICAL STUDIES

G. FLUTTER STUDIES

(1) Flutter characteristics of missile fin and booster fin; validity of theoretical flutter analysis

(2) Panel flutter of tankage, unsupported areas, etc.

DYNAMIC ANALYSIS

I. Theoretical Analysis

II. Experimental Analysis

I. THEORETICAL ANALYSIS

A. SUMMARY

Documentation of dynamic characteristics based on theoretical control system transfer functions. It includes boost phase, directional control system, and roll control system. Objectives of the boost phase analysis are to determine extremes of missile-booster performance. Directional and roll control system analysis is directed toward establishing the stability of the controlled missile and its performance characterisitcs during the various phases of operation over the specifice range of operating conditions.

B. CONTROL SYSTEM TRANSFER FUNCTIONS

(1) Theoretical block diagrams of directional and roll control systems

(2) Amplitude and phase responses of control servos, accelerometers, rate gyros, and networks

C. DIRECTIONAL CONTROL SYSTEM

(1) Static Aeroelastic Effects

a. Equations of motion

1. Effect of aeroelasticity on rigid-body equations of motion, variations with M, altitude, and c.g.
2. Comparison of amplitude and phase responses for rigid body and aeroelastic cases as functions of M, altitude, c.g., and plane of maneuver.

b. Closed Loop Stability

1. Stability of control loop in terms of gain and phase margins.
2. Gain and phase margins of stability as functions of altitude and M for mean c.g. and combined plane.
3. Determination of point of minimum stability.
4. Effect of variation in aerodynamic stability coefficient and gain through rate gyro loop at critical frequency.
5. Gain margin variation with M, altitude, c.g., and rigid and aeroelastic stability coefficients.
6. Effect of aeroelasticity on gain margin.
7. Variation of gain margin with aerodynamic stability coefficient linearized for a range of trim values, at various M and altitudes.

c. Closed Loop Response

1. Steady Maneuverability

Comparison of rigid body and aeroelastic maximum steady state g's in combined plane as function of altitude and c.g.

2. Transient Response Characteristics

   a. Effect of M, altitude, c.g., and combined plane maneuvers.
   b. Percentage overshoot of normal acceleration.
   c. Time required for normal acceleration to reach 80% of steady state value; speed of system response at various flight conditions.
   d. Time required for normal acceleration to reach and remain at 90-110% of steady state value.
   e. Steady state body angle of attack as function of altitude and M.
   f. Overshoot of body angle of attack versus altitude and M.

(2) Dynamic Aeroelastic Effects

a. Pitch rate pickup by rate gyro and acceleration pickup by accelerometer caused by body bending.
b. Natural frequencies of first mode body bending, first mode wing bending, first mode wing torsion, structural damping constant, etc.
c. Amplitude and phase responses as functions of M and altitude.
d. Block diagram of directional control system with essential feedbacks for stability analysis.
e. Stability calculations (amplitude and phase response) at various M and altitudes.
f. Determination of control system stability with rate gyros and accelerometers in specified locations, and determination of allowable locations to maintain stability.
g. Effect of accelerometer location on rate gyro location for neutral stability.
h. Allowable gyro locations as function of M, altitude, aerodynamics, etc.
i. Effect of maximum gain limiting.
j. Effect of air damping.
k. Significance of air and structural damping on control loop stability.
l. Variation of control system gain margins, with and without aerodynamic damping, with structural damping.
m. Control system changes to improve stability.

D. ROLL CONTROL SYSTEM

(1) Rigid-Body Analysis

a. Equations of motion.
b. Stability studies.

   1. Roll Capture phase - effects of M and altitude.
   2. Midcourse guidance phase - effects of M and altitude.
   3. Homing phase - effects of M and altitude.

c. Response studies.

   1. Roll capture phase - capture time as function of altitude and M - effect of free gyro and rate gyro gain.
   2. Midcourse guidance phase - effect of M, altitude, plane of maneuver.
   3. Homingphase - effect of M, altitude, plane of maneuver.

DYNAMIC ANALYSIS (cont.)

(2) Dynamic Aeroelastic Effects

a. Aeroelastic phenomena conditioning roll control system stability.
   1. Dynamic coupling effect on rigid body roll response.
   2. Effect of body torsion response on rate gyros location.
b. Block diagram of roll control system with elements and feedbacks essential for stability analysis.
c. Solution of equations of motion at typical M and altitude conditions.
d. Effect of high frequency aeroelastic phenomena on roll control stability during homing phase - instability conditions.
e. Aeroelastic stability characteristics during midcourse phase - instability conditions.
f. Roll capture phase stability characteristics.
g. Corrective measures for roll control system instabilities.

E. BOOST PHASE DYNAMICS

(1) Equations of missile-booster motion

(2) Boost Phase Trajectories for various cross winds and misalignments

(3) Equation of separation or staging; predicted time of separation as function of misalignment conditions, programming

(4) Motion of missile from instant of separation to initiation of guidance and/or roll capture phase

(5) Normal force coefficients due to angle of attack and pitching moment coefficients due to angle of attack, pitching velocity, lag of downwash, and wing, fin and thrust misalignment as functions of M

(6) Velocity and M versus time, altitude versus downrange, angle of attack versus time, body attitude versus time, and normal acceleration versus time for various conditions of misalignments

(7) Calculated velocity at separation

(8) Lateral distance off guidance beam and beam crossing angle characteristics

(9) Curves of altitude versus downrange, angle of attack versus time, body attitude versus time, and normal acceleration versus time for thrust and surface misalignments causing pitching up and pitching down trajectories

(10) Wind contribution to dispersion

II. EXPERIMENTAL ANALYSIS

A. SUMMARY

Dynamic analysis based on experimentally determined dynamic characteristics of the directional control system, the roll control system during roll capture, midcourse guidance, and homing, and the boost phase. Stability and response characteristics throughout the various phases of operation, and investigation of boost phase trajectory characteristics, wind effects, and dispersion resulting from misalignments.

DYNAMIC ANALYSIS (cont.)

B. CONTROL SYSTEM TRANSFER FUNCTIONS

(1) Comparison of Theoretical and Measured Transfer Functions

a. Frequency response characteristics of networks in circuits, modulator and demodulator amplitude and phase responses, loading effects produced by cascading networks, and non-linearity of modulators and demodulators with level of input.
b. Frequency response tests at d. c. signal level and no signal level.
c. Amplitude and phase response of roll rate gyro, pitch rate gyro, and accelerometer.
d. Amplitude and phase responses of roll capture, midcourse guidance and homing phase configurations of control system.

C. DIRECTIONAL CONTROL SYSTEM

(1) Static Aeroelastic Effects

a. Equations of motion

1. Aerodynamic transfer functions as amplitude and phase responses at typical conditions.
2. Natural frequency and damping ratio for missile as functions of M, altitude, c.g., and single and combined planes.

b. Closed Loop Stability

Gain and phase margins of stability.

c. Closed Loop Response

Steady state maneuverability - maximum g's as functions of M and altitude in single and combined planes.

d. Transient Response Characteristics

1. Effects of M, altitude, c. g., and single and combined planes.
2. Contours of percentage overshoot of normal acceleration.
3. Contours of effective time constant for combined plane maneuvers and forward and aft c. g.
4. Transient airload variations with M, altitude, combined plane, and c. g. location.
5. Maximum predicted airloads in maneuvering.
6. Maximum predicted value of total tail load.

e. Control System Cross-Talk

(2) Dynamic Aeroelastic Effects

a. Stability characteristics versus M and altitude.
b. Effect of rate gyro and accelerometer location.

D. ROLL CONTROL SYSTEM

(1) Rigid Body Analysis

a. Equations of motion.
b. Response studies.

DYNAMIC ANALYSIS (cont.)

1. Roll capture phase
   a. Transient response for typical flight conditions.
   b. Roll capture time.
   c. Maximum wing incidence required to roll capture.
2. Midcourse phase
   a. Transient response for typical flight conditions.
   b. Roll stability characteristics; maximum roll attitude.
   c. Wing incidence for roll stabilization.
3. Homing phase
   a. Transient response for typical flight conditions.
   b. Maximum and steady state wing incidence for roll control.

c. Stability studies

1. Measured transfer functions.
   Range of stability margins for roll capture, midcourse, and homing phases.
2. Low amplitude stability and end instrument non-linearity effects.
   Effect of servo deadspace and velocity limiting on phase lag and servo frequency response; limit cycle oscillation effect; rate gyro saturation limits; steady-state oscillation characteristics; rate gyro limiting effects; critical deadspace magnitude; stability versus input.

(2) Dynamic Aeroelastic Effects

a. Amplitude and phase responses of rigid body rolling rate and body torsion.
b. Gain margins of stability; critical frequencies and altitudes.
c. Airloads resulting from aeroelastic vibrations.
d. Correlation of theory and flight test data.

E. BOOST PHASE DYNAMICS

(1) Separation Velocity

Effects of temperature, wind, launcher angle, etc. on separation velocity.

(2) Trajectories

a. Effects of gravity, thrust misalignment, wing misalignment, booster fin misalignment, and wind or trajectory and orientation at end of boost.
b. Dispersion characteristics, probability of guidance capture.

STRUCTURAL CRITERIA AND FLIGHT PHASE DESIGN AIRLOADS

A. SUMMARY

Flight-phase aerodynamic loads, including effects of aeroelasticity, required for the structural design of the missile. Airloads are required for those conditions which contribute to the critical over-all structural load for the various airframe components when combined with inertia loads and structural-strength properties as affected by structural temperatures, and are limited

to those conditions for which the critical structural loadings are not exceeded by loading conditions other than those in the flight phase. Loading conditions for nominal, hot, and cold days are required.

Design criteria and actual loads are established to permit development of the actual detail design. Margins of safety are computed from the actual design.

B. CRITERIA

(1) Factors of Safety (Use minimum factors of safety; justify with extensive static and proof testing.)

a. Missile airframe.

With personnel	(yield and ultimate)
Without personnel	(yield and ultimate)
Pressure vessels	(yield and ultimate)

(2) Allowables (Based on detail knowledge of materials.)

a. Temperature - vary as a function of time and environment.
b. Fatigue - panel flutter; load repetition due to pre-flight testing; rapid changes in load.

(3) Pressure Schedules

Optimize to obtain stabilization, minimum pressurizing gas requirements.

(4) Gust and Wind Shear Data

a. Discrete and power spectral inputs. Standard design values; ICAO and Cambridge Development Center data.

(5) Aerodynamic Data

a. Pitch, roll, and yaw data - obtain from wind tunnel data.
b. Pressure distributions - obtained from wind tunnel data.
c. Jet or rocket motor effectiveness data - obtained from propulsion systems tests. Influence coefficients are required.

(6) Alternate Mission Trajectories

a. Effect of guidance system.
b. Parametric studies to select optimum trajectories.

(7) Structural Tests and Data

a. Static tests to establish MS.
b. Dynamic tests to establish mode shapes and frequencies.

C. DESIGN CONDITIONS

(1) Flight Conditions

a. Launch phase (Start eng. to clearing equipment)

Configuration
Weights and c. g.
Pressure schedule

STRUCTURAL CRITERIA AND FLIGHT PHASE DESIGN AIRLOADS (cont.)

Thrust build-up
Dynamic loads
Hold-down loads
Ground gust and winds

b. Booster phase

Start	Configuration - determines load distribution
	Weights - cause inertia and concentrated loads
	Press. schedule - determines gas required, tankage design
	Temperature - determines allowables
	Thrust and thrust angle - fixes steady state loads
	Dynamic loads (thrust - autopilot) - determines stability requirements
	Thrust trimming loads - determines stability requirements
Intermediate	Gust and wind shear - determines autopilot char.
	Jettisoning - causes transients
	Air loads and distributions - fixes detail design
	Body flexibility - determines certain autopilot characteristics
	Thermal-elasticity - determines detail design: material selection.
End	Autopilot response to gusts - determines transient loads.

c. Midcourse or Second Stage Phase

Start

Intermediate

End

d. Burn-out or Coast Phase

e. Re-entry Phase

(2) Ground Conditions

a. Factory handling

Configuration
Weights and c. g.'s
Pressure schedules
Shock and vibration
Load factors

b. Launching site handling

Same items as a.

STRUCTURAL CRITERIA AND FLIGHT PHASE DESIGN AIRLOADS (cont.)

c. Shipping

Truck Rail Ship Airplane	Same detail items as a.

d. Firing stand

Configuration
Weight and c. g.'s
Pressure schedules
Load factors
Fueling loads (unsymmetrical firing)
Hold-down loads
Ground gusts and winds
Dynamic thrust loads

GUST LOADS

A method of accounting for gust loads as suggested by WADC is given below. It is applied only to missiles with aerodynamic surfaces and results in a conservative design.

The missile should be considered subject to the attack of a gust of design speed at all missile operating speeds and altitudes. The design gust speed may be taken as 50 fps at all points on the trajectory below 35,000 ft. For points of the trajectory above 35,000 ft., the gust speed may be taken as 50 fps reduced by the multiplying factor of the ratio of F (z) at the altitude in question to F (z) at 35, 000 ft.* The missile should be analyzed for the actual time history of flight. The gust load factor formula for basic use is suggested as follows:

Gust Load Formula

$$N = 1 \pm \frac{K_g U_{de} a V_e}{498 \; W/S}$$

Where V_e = Equivalent airspeed in knots

U_{de} = Design gust speed

W/S = Wing loading in pounds per square foot

a = Rate of change of missile normal force coefficient with angle of attack (per radian) corrected for Mach number effect and elasticity.

K_g = Dimensionless gust factor which accounts for the accelerated motion of the missile and the time lag of the buildup of aerodynamic lift. This is shown in Fig. 9.1. The supersonic curve may be used for the transonic region.

*The function F (z) should be included here using its proper name.

Gust in Maneuvering Flight

The missile should be examined for a gust attack during maneuver. This combined condition should be considered for all phases of the missile flight trajectory. The design gust speed for this case may be equal to 50% of the design gust speed determined above.

Gust Load History

In lieu of the gust load condition given above, the contractor may calculate the complete missile temporal response considering the missile penetrating a single versinusoidal gust of 25 wind chord lengths. The gust speed must be in accordance with the above.

Dynamic Gust Loads

In all cases where the ratio of the temporal duration of a single versinusoidally varying gust of 25 chord lengths to the natural period of vibration of a major structural component, or of the period of missile pitching oscillation, falls between 0.4 and 2.5, there exists the possibility of a critical stress occurring from a dynamic "over-swing" condition. In such event, the response of the structure to a versinusoidal forcing function must be considered.

CHECKOFF LIST FOR DETAIL DESIGN

The following check list can be used when designing and/or checking a component or assembly:

A. Select the right material, considering:

1. High-strength alloys for structures
2. Light materials for secondary structures
3. Low-density space fillers
4. Synthetics and light weight plastics
5. Magnesium alloys
6. Titanium alloys
7. Special materials for special jobs
8. Cladded or sandwich materials
9. Economics of initial cost, processing and finishing
10. Strategic value of material
11. Limitations of aluminum for sliding or rotating joints.

B. Increase design efficiency by:

1. Taking advantage of static tests
2. Using shortest practical members
3. Using efficient sections

CHECKOFF LIST FOR DETAIL DESIGN (cont.)

4. Designing for tension
5. Making parts do several jobs
6. Avoiding combined loads of different types
7. Not overdesigning nonstructure
8. Questioning the conventional
9. Selecting optimum type of structure by reference to previous studies, standard sources such as NACA data, etc.
10. Using 90% probability values where applicable
11. Using models; physical and functional mockups
12. Taking advantage of directional properties of materials
13. Using appropriate sinks and sources to relieve thermal stresses
14. Using properly selected lock nuts/washers
15. Using most liberal tolerances possible
16. Preventing relative movement between parts such as stringers and stiffeners
17. Using maximum possible bend radii on sheet metal parts
18. Allowing for adequate clearance of parts moving relative to each other when elastically deformed under load
19. Eliminating stress concentrations.

C. Eliminate unnecessary material and parts by:

1. Using minimum number of parts
2. Eliminating duplicating parts
3. Eliminating unnecessary special features
4. Eliminating joints and splices
5. Using beads and other integral reinforcements
6. Considering thinner gages
7. Avoiding use of lock wires
8. Integration of sub-systems.

D. Use light weight fastening devices, considering:

1. Clevis bolts in shear
2. Hi-shear rivets
3. Flat-head pins
4. Tinnerman or other special fasteners
5. Roll pins
6. Metal bonding adhesives.

E. Specify light weight fabrication, considering:

1. Dimpled joints
2. Flash welded joints
3. Welded joints
4. Minimum flange dimensions and lap splices instead of butt splices
5. Stampings, sheet-metal parts
6. Removal of excess metal from forgings and castings
7. Laminated phenolics; plastics
8. Comparing forging vs casting vs extrusions vs builtup fabrication
9. Electroforming.

CHECKOFF LIST FOR DETAIL DESIGN (cont.)

F. Design for complete environment by considering:

1. Design for temperature, humidity, aridity, salt spray/corrosion, pressure/altitude, vibration, mechanical/thermal shock, sunlight, rain, snow, sleet, ice, sand, dirt, dust, abrasives, grease, oil, fungus
2. Structural damping
3. Stiffness
4. Erosion
5. Proximity of unlike materials
6. Adequacy of finish

G. Design for high temperature by considering:

1. Temperature history, level uniformity, etc.
2. Expected service life at temperature
3. Deformation allowable
4. Corrosion and oxidation
5. Changes in material properties
6. Maintenance permitted
7. Thermal characteristics (conductivity, expansion, capacity)
8. Cost and availability of special materials

H. Design for processing by considering:

1. Screw machine vs stamping vs die casting for piece parts
2. Shell molding; frozen mercury precision casting
3. Spinning vs stamping vs stretch forming vs rubber die forming
4. Elimination of special finishes
5. Use of minimum number of secondary treatments
6. Omission of welding thick to thin sections
7. Limitation of welding of tube clusters to six or less members

I. General considerations:

1. Check conformance to specification requirements
2. Check conformance to qualified and/or approved parts lists
3. Use shelf items wherever possible
4. Use commercial quality components where possible without jeopardizing reliability
5. Establish test program to check special features
6. Provide for interchangeability only as required
7. Compare expendability to reliability
8. Provide safety features; explosion proof design

J. Design for economic manufacture and maintenance by:

1. Using standard voltages, frequencies, sheet metal thicknesses and sizes, connectors, etc.
2. Providing adequate color coding, markings, stenciling, etc.
3. Providing for easy access and replacement
4. Providing for water drainage of cavities

FIGURE 9.1 GUST FACTOR VS MASS RATIO

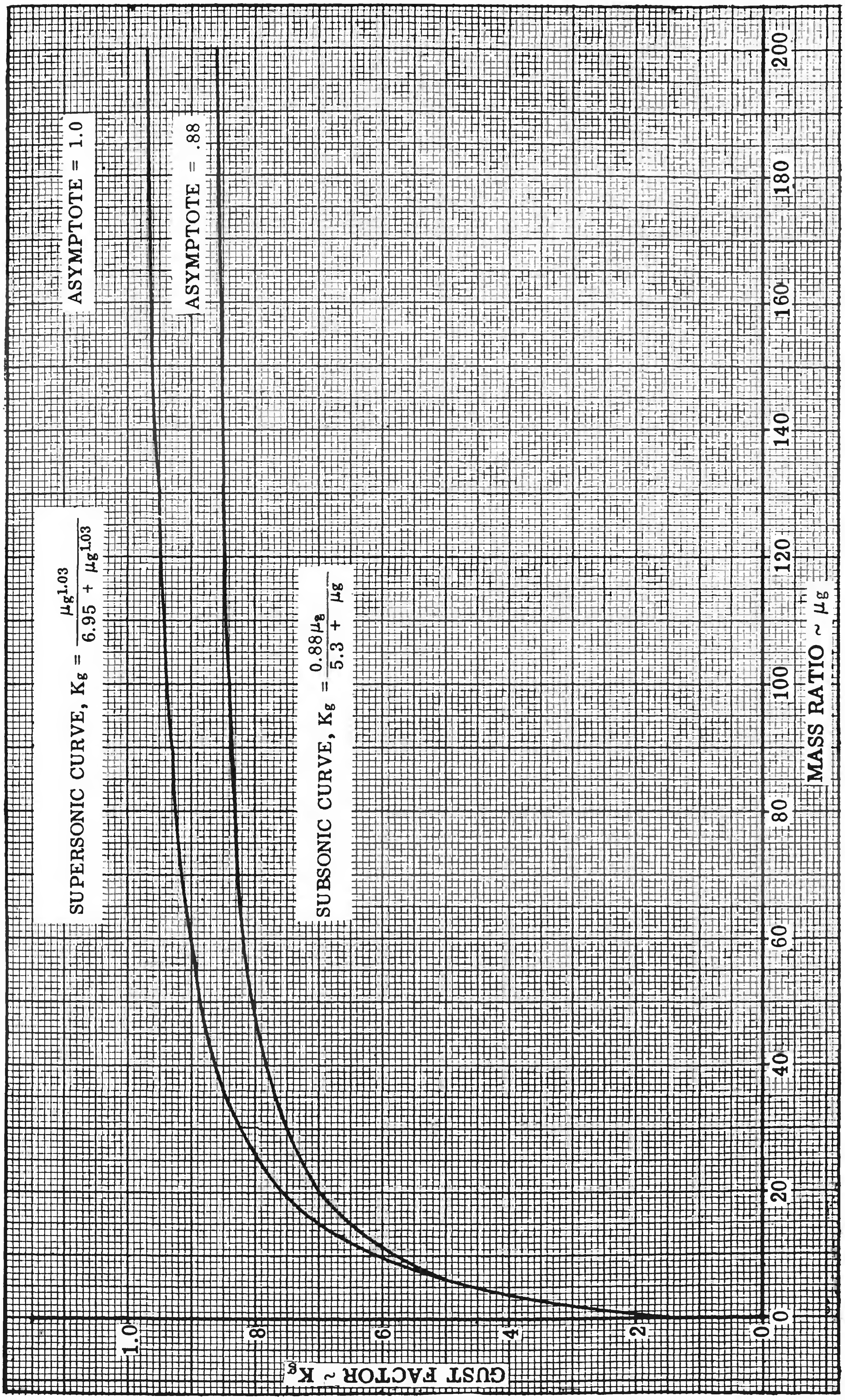


FIGURE 9.2 TYPICAL MANUFACTURING TOLERANCES FOR GUIDED MISSILES

Struts	Ordinate ± 0.032
Diffusers	Ordinate ± 0.032 (on radius)
Innerbodies	Ordinate ± 0.032 (on radius)
Nozzles	Ordinate ± 0.064 (on radius)
Body O.D.'s	Ordinate ± 0.064 (on radius)
Innerbody displacement and concentricity relative to lip of diffuser for multiple shock entry designs	± 0.032
Innerbody angular misalignment	± 1/2°
Longitudinal body station location	$\pm \frac{1}{32}$
Longitudinal location of aerodynamic surfaces, scoops and exit nozzles	± 0.25
Normality of mating surfaces	± 0° 5'
Diameter of mating surfaces	± 0.010
Out of round of mating surfaces	± 0.06 T.I.R.
Thickness of surfaces	± 2% of total specified thickness or 0.30, whichever is larger
Aerodynamic surface planform dimensions	± 0.064
Clearance - aerodynamic surfaces to body O.D.'s at any point	
Movable surfaces	0.06 to 0.25
Fixed surfaces	0.01 to 0.20
Fairness - differences between actual deviations from theoretical contour	0.32 in any 3" of length
Camber (all surfaces) maximum deviation of the mean thickness line at midchord from theoretical chord plane through leading and trailing edge	0.3% chord or 0.03, whichever is larger
Radius of all corners in plan view unless otherwise specified	0.10 ± 0.05
Wing tip radii, plan view	0.25 ± 0.06
Leading and trailing edge thickness in cross section all surfaces	$0.04 \begin{smallmatrix} +0.010 \\ -0.015 \end{smallmatrix}$
if rounded, radius	$0.020 \begin{smallmatrix} +0.005 \\ -0.015 \end{smallmatrix}$
if square, break corners	0.005 to 0.015

FIGURE 9.3 TYPICAL TOLERANCES OBTAINABLE WITH MACHINE WORK

LATHE OPERATIONS

	Tolerance
Rough Turning	
1/4" to 1/2" diameter	0.005
1/2" to 1" Diameter	0.007
Over 1" diameter	0.015
Finish turning	
1/4" to 1/2" diameter	0.002
1/2" to 1" diameter	0.003
1" to 2" diameter	0.005
Over 2" diameter	0.007
Rough boring	
1" to 2" diameter	0.008
Over 2" diameter	0.010
Finish boring	
1" to 2" diameter	0.002
Over 2" diameter	0.005

MILLING OPERATIONS

Single Surfaces	+0.002 to +0.003; - 0.000
Two or more surfaces	0.005
Straddle milling	-0.003 to -0.005; + 0.000
Form milling	0.005
End	
1/4" to 1/2" width	0.004
1/2" to 3/4" width	0.006
3/4" to 1" width	0.008
Depth of cut	0.005

Note: While 0.002 is feasible on most operations, 0.005 tolerance is more desirable from standpoint of economy of manufacture. For hand milling allow slightly larger tolerances.

Spline milling	
Width	0.005
Width (to be shaved)	0.005 to 0.010
Shallow keyways	0.002
Profiling	
Hand-simple contours	0.004
Hand-complicated contours	0.008
Automatic	0.005 to extreme of 0.015
Thread milling	
Pitch diameter	0.001 to 0.002
O.D. & min. diameter	0.002 to 0.004

DRILLING OPERATIONS

Assuming use of suitable jigs

Drill size	Minimum Tolerances	
#60 to #30	-0.000	+0.002
#30 to #1	-0.000	+0.003
1/4" to 1/2"	-0.000	+0.004

FIGURE 9.3 TYPICAL TOLERANCES OBTAINABLE WITH MACHINE WORK (cont.)

1/2" to 3/4"	-0.000 +0.005
3/4" to 1"	-0.000 +0.007
1" to 2"	-0.000 +0.010
SHAPING OPERATIONS	
Vertical - width and end	0.004
Horizontal	0.005 to 0.010
PLANING OPERATIONS	
Comparatively large pieces	0.005 to 0.010
GRINDING OPERATIONS	
Cylindrical grinding	0.0003 to 0.0005
Surface grinding	0.001
Surface grinding (vertical inch)	0.001 to 0.002
Automatic roll grinding	0.00025

Note: For best productive capacity in surface grinding, use a tolerance of 0.002 and for cylindrical grinding a tolerance of 0.0005. Gage grinding - surface and cylindrical 0.00025.

HONING AND LAPPING OPERATIONS	
Horizontal spindle honing	0.0002
Internal honing	0.0003
Cylindrical surface lapping	0.0001
BORING OPERATIONS	
Single point boring tool; rough drilled undersize and finish bored	0.00025
Using accurate spotting tool; rough drilled undersize and reamed with undersize end mill,	0.0005 to 0.001
BROACHING OPERATIONS	
Medium sized broaches	0.0005 to 0.003
Vertical surface broaches	0.003
Burnishing broaches	0.0001 to 0.001
TURRET LATHE OPERATIONS	
Diameters	0.002
Shoulders	0.005
AUTOMATIC SCREW MACHINE OPERATION	
Turning with box tool	0.003
Shoulders	0.003 to 0.005
Forming tools	
Width 3/4	0.003
Width 3/4" to 1-1/2"	0.004
Threading	
O.D.	0.003
Pitch, diam.	0.002

FIGURE 9.3 TYPICAL TOLERANCES OBTAINABLE WITH MACHINE WORK (cont.)

Hollow milling	
3/16" to 1/2" diameter	0.006
1/2" to 3/4" diameter	0.008
3/4" to 1" diameter	0.010
Reaming	
Up to 1/2" diameter	0.001
1/2" to 1" diameter	0.0015
Drilling	
Same as given above under Drilling Operations	
REAMING OPERATIONS	
Hand reaming	
Up to 1" diameter	0.001
Over 1" diameter	0.002
Machine reaming	
Up to 1/2" diameter	0.0005
1/2" to 1" diameter	0.00075 to 0.001
Over 1" diameter	0.0015
TOLERANCES ON CENTER DISTANCES	
On important work with jigs, tolerance between holes	0.001
Without jigs	0.005
THREADS	
Lathe Cut - pitch diameter	0.0015 - 0.002
Milling - pitch diameter	0.001; O.D. & R.D. : 0.002
For interchangeable mfg.	P.D. : 0.002
	O.D. : 0.004
	R.D. : 0.004

FIGURE 9.4 PRINTED CIRCUIT TOLERANCES

1) UNPLATED HOLES — Diameter Tolerances

Drilled	±.002
Reamed	±.001
Counterbored or flycut (dias. from 5/16" to 4")	±.005

		PAPER BASE	GLASS BASE
Punched * (1/16" thick)	Up to 1/4" dia.	±.003	±.003
	1/4" to 1/2" dia.	±.003	±.004

* Punched Slots and Notches .. use tolerances as above considering both length and width as hole diameters.

FIGURE 9.4 PRINTED CIRCUIT TOLERANCES (cont.)

1/2" to 1" dia.	±.004	±.004
over 1" dia.	±.005	

Add ± .001 to above for thicknesses of 3/32" through 1/8"

Routed Slots and Notches up to 2"	±.005
Milled or Broached Slots and Notches up to 2"	±.003

2) PLATED HOLES —

ADD the following tolerances to tolerances shown above on drilled or punched holes:

Drilled, paper base	±.004
Drilled, glass base	±.005
Punched, paper base	±.005

3) LOCATION TOLERANCES ON DIMENSIONS BETWEEN HOLES (Plated or Unplated)

Drill by eye or "throw away" drill jigs	±.015
Drill by pantograph or short run drill jigs	±.010
Drill by jig bored hardened drill jigs	±.005
Punch by Tape-Programmed Punching Machine	±.005
Punch by Weidemann short run template	±.010
Punch by Weidemann steel jig bored template	±.005
Punch by standard piercing die*... on dimensions up to 2"	±.005

Add ±.001 for every inch over 2"

4) HOLE TO PATTERN TOLERANCES (One Side)

	UNPLATED HOLE	PLATED-THRU HOLE
Drill by eye to pattern (sample runs only)	within .010 of center	
Drill by temporary drill jigs or pantograph	within .020 of center	within .020 of center
Drill by permanent jigs	within .015 of center	within .015 of center
Drill by special visual alignment jigs	within .005 of center	
Punch by Tape-Programmed Punch	within .015 of center	within .015 of center
Punch by Wiedemann short run template	within .020 of center	within .020 of center
Punch by Wiedemann steel jig bored template	within .015 of center	within .015 of center
Punch by standard piercing die	within .015	within .015

*A high precision ground die will reduce this by ±.002.

FIGURE 9.4 PRINTED CIRCUIT TOLERANCES (cont.)

5) <u>FRONT TO BACK PATTERN TOLERANCES</u> (Alignment)

	REGULAR	PREMIUM
Where there are no plated holes	within .025	within .015
With plated holes	within .020	within .015
With Melacon	within .020	within .015

6) <u>CIRCUIT PATTERN TO OUTSIDE DIMENSION</u>

Routed edges	regular ±.015; premium±.010
Turned O.D.	regular ±.015; premium ±.010
Blanked edges	±.015
Milled edges	±.015

All registry tolerances are predicted on usage of an accurate black and white master drawing made on dimensionally stable drafting material.

7) <u>OVERALL DIMENSION TOLERANCES</u>

Sawed edges	by eye ± 1/32; with jig ±.010
Routed edges	regular ± .010; premium±.005
Turned O.D.	regular ±.005; premium ±.003
Blanked edges	±.003 plus ±.001 per inch of length
Milled edges	±.005
Sheared	±1/32

8) <u>HOLES TO OUTSIDE DIMENSION TOLERANCES</u>

With progressive die		±.010
With compound die		±.005
Drilled & Routed		±.010
Drilled & Routed, premium		±.005
Saw by eye		±1/32
Saw by jig		±.015
I.D. to O.D.:	Regular T.I.R.*	.010
	Premium T.I.R.*	.003

9) <u>LINE WIDTH AND SPACING TOLERANCES</u>

No plating	regular ±.010; premium ±.005	Exclusive of nicks.
With plating	regular ±.010; premium ±.008	

Minimum line width and/or spacing:	Unplated	.020"
	Plated	.020"
	Melacon	.025"

10) <u>PLATING TOLERANCES</u>

Guaranteed minimum thickness only.

11) <u>NICKS, PINHOLES AND SCRATCHES</u>

Acceptable if they do not reduce line width by more than 33%.

*Total indicated runout.

FIGURE 9.4 PRINTED CIRCUIT TOLERANCES (cont.)

12) WARP

Pattern on ONE side:

1/16" stock thickness	.025" per inch of length
3/32" stock thickness	.020" per inch of length
1/8" stock thickness	.012" per inch of length
1/4" stock thickness	.006" per inch of length

Pattern on TWO sides:

All stock thicknesses	.005" per inch of length

13) MECHANICAL AND ELECTRICAL PROPERTIES

See NEMA Standards of Base Materials.

In special cases exceptions to the above tolerances may be made with factory approval. It must be assumed that the foregoing data will be revised as methods and processes of the industry improve.

FIGURE 9.5 AVAILABLE FORMS OF TITANIUM AND TITANIUM ALLOYS

	Sheet	Strip	Plate	Wire	Bars	Rod	Forging Billets	Forgings	Welded Tubing
Commercial Titanium									
Ti-75 A	x	x	x	x	x	x	x	x	x
MST Grade III	x	x	x	x	x	x	x	x	
Titanium Alloys									
Ti-150 A			x	x	x		x	x	
Ti-150 B	x	x	x	x					
Ti-170 A			x		x		x	x	
Ti-175 A			x		x		x	x	
MST (3 Al-5 Cr)									
L 2748			x		x	x	x	x	
MST (2.5 Fe-2.5V)									
L 2841	x	x			x		x	x	
MST (2 Al-2 Fe)									
L 2052	x	x			x		x	x	
RC-130 A	x								
RC-130 B		x		x	x		x	x	
RC-A 110 AT	x (>0.1)		x		x			x	

FIGURE 9.6 ALUMINUM STANDARD PRODUCTS

Alloy	Sheet	Plate	Wire	Rod	Bar	Rolled Shapes	Extruded Shapes, Tube and Pipes	Drawn Tube and Pipe	Rivets	Forgings
EC 1			*	*	*	2				
No. 2 EC							13			
1100	*	*	*	*	*				*	*
2011			*	*	4					
2014				*	*	*	*			*
Alclad 2014	*	*								
2017			*	*	*					
2018										*
2024	*	*	*	*	*		*	*	*	
Alclad 2024	*	*								
2025										7
2117			5	8					*	
2218										*
3003	*	*	*	*	*		*	*		
Alclad 3003	*	*						*3		
3004	*	*								
Alclad 3004	*	*								
4032										*
4043			*	6						
5050	*	*						9		
5052	*	*	*	*	*			9		
5056			*	8					*	
Alclad 5056			*	6						
5154			12							
6053			5	10					*	
6061	*	*	*	*	*	*	*	*	*	
6062							11	9		
6063							*	*		
7072			*							
7075	*	*	*	*	*		*			*
Alclad 7075	*	*								
7277									*	
No. 11 Brazing	*									
No. 12 Brazing	*									
No. 21 Brazing	*									
No. 22 Brazing	*									
No. 713 Brazing	*									
No. 716 Brazing			*							
No. 718 Brazing			*							

* Products in routine commercial production
1 Electrical conductor grade.
2 Channel bus only.
3 Coating on inside only.
4 Available in hexagon only.
5 Rivet wire only.
6 Redraw rod only.
7 Propeller blades only.
8 Rivet rod and redraw rod only.
9 Tube only.
10 Rivet rod only.
11 Extruded shapes and tube only.
12 Welding wire only.
13 Bus bar only.

FIGURE 9.7 ALLOY DESIGNATIONS FOR WROUGHT ALUMINUM

ALUMINUM ASSOCIATION SYSTEM

A new system of alloy designations for wrought aluminum has been developed and adopted by the Aluminum Association and its member companies. The new system overcomes the inadequacies of the various commercial systems previously used and was effective on October 1, 1954.

Under the new system wrought aluminum and wrought aluminum alloys are designated by a four digit number. The first digit indicates the alloy group. The last two digits identify the alloy or the aluminum purity. The second digit indicated modifications of the original alloy or impurity limits.

DESIGNATIONS FOR ALLOY GROUPS

Aluminum--99.00% minimum and greater		1xxx
	Major Alloying Element	
Aluminum Alloys grouped by major Alloying Elements	Copper	2xxx
	Manganese	3xxx
	Silicon	4xxx
	Magnesium	5xxx
	Magnesium and Silicon	6xxx
	Zinc	7xxx
	Other element	8xxx
Unused Series		9xxx

FIGURE 9.7 ALLOY DESIGNATIONS FOR WROUGHT ALUMINUM (cont.)

TEMPER DESIGNATIONS

The temper designation system in effect since December 31, 1947 is being continued without change. It indicates mechanical or thermal treatment of the alloy. The temper designation follows the alloy designation and is separated from it by a dash, e.g. 7075-T6. Note that some temper designations apply only to wrought products, others to cast products, but most apply to both. Additional digits to the right indicate variations in the basic treatment.

-F As fabricated

-O Annealed and recrystallized (wrought only).

-H Strain hardened (wrought only).

- -H1, plus one or more digits. *Strain hardened only.
- -H2, plus one or more digits. *Strain hardened, then partially annealed.
- -H3, plus one or more digits. *Strain hardened, then stabilized.

-W Solution heat treated - unstable temper.

-T Treated to produce stable tempers other than -F, -O or -H.

- -T2 Annealed (cast only).
- -T3 Solution heat treated, then cold worked.
- -T4 Solution heat treated and naturally aged to a substantially stable condition.
- -T5 Artifically aged only.
- -T6 Solution heat treated, then artificially aged.
- -T7 Solution heat treated, then stabilized.
- -T8 Solution heat treated, cold worked, then artificially aged.
- -T9 Solution heat treated, artificially aged, then cold worked.
- -T10 Artificially aged, then cold worked.

*Second digit indicates final degree of strain hardening, i.e. 2 is 1/4 hard, 4 is 1/2 hard, 6 is 3/4 hard, 8 is full hard.

FIGURE 9.7 ALLOY DESIGNATIONS FOR WROUGHT ALUMINUM (cont.)

OLD TO NEW CONVERSION

OLD①	NEW	OLD①	NEW
99.3②	1230	A50S, K153, **R305**	5005
99.35, R995	1235	XD50S	X54C5
99.6, CD1S	1160	**A51S**	6151
99.75③	1175	XB51S	X6251
99.87, EB1S	1187	**J51S**, K160	6951
EC④	EC	**52S**	5052
AA1S	1095	F52S	5652
BA1S	1099	53S	6053
CA1S	1197	B53S	6253
AB1S	1085	XD53S	X6453
EB1S, **99.87**	1187	E53S	6553
FB1S	'090	**A54S**	5154
AC1S	1070	B54S	5254
BC1S	1080	**X55S**	X5055
CC1S, **R998**	1180	**56S**	5056
JC1S	1075	XC56S	X5356
AD1S	1050	**C57S**, K157	5357
BD1S	1060	**61S**	6061
CD1S, **99.6**	1160	**62S**	6062
ED1S	1150	**63S**	6063
AE1S	1030	66S	6066
BE1S	1145	70S	7070
2S	1100	**72S**	7072
3S	3003	**75S**	7075
4S	3004	B77S	7277
XA5S	X3005	XA78S	X7178
11S	2011	XB80S	X8280
14S, R301 Core	2014	K112	8112
XB14S	X2214	K143, C43S, **44S**	4343
XC16S	X2316	K145, **43S**	4043
17S	2017	K155, A50S, **R305**	5005
A17S	2117	K157, **C57S**	5357
18S	2018	K160, **J51S**	6951
B18S	2218	K162, **R306**⑤	6003
F18S	2618	LK183	5083
24S	2024	K186	5086
25S	2025	**R301 Core, 14S**	2014
B25S	2225	**R305**, K155, A50S	5005
32S	4032	**R306**, K162⑥	6003
43S, K145	4043	**R308**⑥	1130
C43S, **44S**, K143	4343	**R399**	8099
XE43S	X4543	**R995, 99.35**	1235
44S, C43S, K143	4343	**R998**, BC1S	1080
45S	4045		
50S	5050		

NEW TO OLD CONVERSION

NEW①	OLD	NEW①	OLD
EC④	EC	**4343**	C43S, 44S, K143
1030	AE1S	X4543	XE43S
1050	AD1S	**5005**	A50S, R305, K155
1060	BD1S	**5050**	50S
1070	AC1S	**5052**	52S
1075	JC1S	**X5055**	X55S
1080	BC1S, R998	**5056**	56S
1085	AB1S	5083	LK183
1090	FB1S	5086	K186
1095	AA1S	**5154**	A54S
1099	BA1S	5254	B54S
1100	2S	X5356	XC56S
1130⑥	R308	**5357**	C57S, K157
1145	BE1S	X5405	KD50S
1150	ED1S	5652	F52S
1160	CD1S, 99.6	**6003**⑤	R306, K162
1175③	99.75	6053	53S
1180	CC1S	**6061**	61S
1187	EB1S, 99.87	**6062**	62S
1197	CA1S	**6063**	63S
1230②	99.3	6066	66S
1235	R995, 99.35	**6151**	A51S
2011	11S	X6251	XB51S
2014	14S, R301 Core	6253	B53S
2017	17S	X6453	XD53S
2018	18S	6553	E53S
2024	24S	**6951**	J51S, K160
2025	25S	7070	70S
2117	A17S	**7072**	72S
X2214	XB14S	**7075**	75S
2218	B18S	X7178	XA78S
2225	B25S	7277	B77S
X2316	XC16S	**8099**	R399
2618	F18S	8112	K112
3003	3S	X8280	XB80S
3004	4S		
X3005	XA5S		
4032	32S		
4043	43S, K145		
4045	45S		

Alclad 3003 .... 3003 clad with 7072
Alclad 3004 .... 3004 clad with 7072
Alclad 2014 .... 2014 clad with 6003
Alclad 2024 .... 2024 clad with 1230
Alclad 5050 .... 5050 clad with 7072
Alclad 5055 .... 5055 clad with 7072
Alclad 5056 .... 5056 clad with 6253
Alclad 6061 .... 6061 clad with 7072
Alclad 7075 .... 7075 clad with 7072

NOTES Reflector Sheet and Brazing Sheet will continue to be designated by simple prefix numbers, e.g. No. 21 Brazing Sheet.

①Alloys in bold type are produced by Reynolds.
②Cladding on Alclad 2024 (Alclad 24S).
③Cladding on No. 2 Reflector Sheet.
④EC - The designation for electrical conductor metal is not being changed since it is so firmly established in the electrical industry.
⑤Cladding on Alclad 2014 (R301 and Alclad 14S)
⑥No. 1 Reflector Sheet.

FIGURE 9.8 TYPICAL PROPERTIES OF SOME HYDRAULIC FLUIDS

	Oronite 8515	Oronite 8200	MIL-O-5606	OS-45
Specific gravity				
-65 deg F	0.982	—	—	—
4-20 deg C	—	0.931	—	—
60 deg F	0.930	—	—	—
350 deg F	0.809	—	—	—
Flash point (deg F)	410	405	—	—
Fire Point (deg F)	450	450	—	—
Pour point (deg F)	>-100	>-100	-90	-85
Neutralization number	0.02	0.05	—	—
Viscosity (centistokes)				
-65 deg F	2357	2490	2130	2230
100 deg F	24.3	34.4	1.4	12.1
210 deg F	8.11	11.78	—	3.95
400 deg F	2.64	3.82	1.9	1.2
Vapor pressure at 400 deg F (mm Hg)	1	1.2	230	4.7
Oxidation & corrosion (72 hr at 400 deg F; metal weight change in mg/cm^2)				
Aluminum	-0.04	-0.02	must	< 0.1
Steel	+0.04	-0.05	meet	0
Copper	-0.05	+0.04	de-	0
Silver	-0.06	-0.04	tailed	0
Evaporation (per cent after 6 1/2 hr)			test	—
			re-	—
350 deg F	6.1	—	quire-	—
400 deg F	—	22.3	ments	—
Hydrolytic stability (48 hr at 200 deg F)				
Copper weight change (mg/cm^2)	0	-0.03	—	0.1
Insolubles (per cent)	-0.04	0.05	—	0.03
Viscosity change				
at 100 deg F	-1.2	+2.1	—	—
at 210 deg F	—	—	—	-0.3

FIGURE 9.9 PROTECTIVE COATING CHEMICALS FOR PAINT-BONDING ON ALUMINUM

Method of Application	Type of Coating	Object of Coating	Typical Metal Products Treated	Scale of Production	Equipment Notes	Coating Time	Coating Wt. Range
Spray processes	Amorphous phosphate	Improved paint adhesion and corrosion-resistance	Primarily aluminum products of similar design such as aircraft and aircraft parts; bazookas (rocket launchers), rocket motors, etc.	Large or small volume; large, small or medium work; continuous or intermittent.	Power spray washer with required number of stages. Cleaning and rinsing stages can be of mild steel. Coating stage should be of stainless or stainless-clad steel, or Koroseal-lined.	20-30 secs.	100-200
		Improved paint adhesion and corrosion-resistance	Primarily aluminum strip or sheet stock.	Large or medium volume; continuous	Power spray washer with required number of stages. Cleaning and rinsing stages can be of mild steel. Coating stage should be of stainless or stainless-clad steel, or Koroseal-lined.	20-30 secs.	100-200
	Chromate	Improved paint adhesion and corrosion-resistance	For unpainted or partly painted wrought aluminum products; and for aluminum castings and forgings.	Large or small volume; large, small or medium work; con-continuous or intermittent.	Power spray washer with required number of stages. Cleaning and rinsing stages can be of mild steel. Coating stage should be of stainless or stainless-clad steel, or Koroseal-lined.	20 sec.	100-200

Spray processes (cont.)	Chromate	Improved paint adhesion and corrosion-resistance	For unpainted or partly painted wrought aluminum products; and for aluminum castings and forgings.	Large or small volume; large, small or medium work; continuous or intermittent.	Power spray washer with required number of stages. Cleaning and rinsing stages can be of mild steel. Coating stage should be of stainless or stainless-clad steel, or Koroseal-lined.	20 sec.	100-200
Dip processes	Amorphous phosphate	Improved paint adhesion and corrosion-resistance	Fabricated products; struts; castings; forgings, etc.; aircraft and aircraft parts, bazookas (rocket launchers), rocket motors, etc.	Medium or small volume; large or small work.	Immersion tanks of suitable capacity. Cleaning and rinsing stages can be of mild steel. Coating stage should be of stainless or stainless-clad steel, or Koroseal-lined.	1-2 mins.	100-200
	Chromate	Improved paint adhesion and corrosion-resistance	Fabricated products; struts; castings; forgings, etc.; aircraft and aircraft parts, bazookas (rocket launchers), rocket motors, etc.	Large or small volume; large, small or medium work; continuous or intermittent.	Immersion tanks of suitable capacity. Cleaning and rinsing stages can be of mild steel. Coating stage should be of stainless or stainless-clad steel, or Koroseal-lined.	2-5 mins.	100-200

FIGURE 9.10 PROTECTIVE COATING CHEMICALS FOR PAINT-BONDING ON STEEL (cont.)

Method of Application	Type of Coating	Object of Coating	Typical Metal Products Treated	Scale of Production	Equipment Notes	Coating Time	Coating Wt. Range
	Chromate	Improved paint adhesion	Sheet steel products.	Large or small volume; large or small work.	Power spray washer with required number of stages. Cleaning and rinsing stages can be of mild steel. Coating stage can be of heavy mild steel or stainless steel.	1-2 mins.	
Dip processes	Zinc phosphate	Improved paint adhesion	Stampings, castings, forgings, or fabricated sheet metal parts: meter cases; cabinet hardware; etc.; rockets, vehicular sheet metal, bolts and links.	Small, medium, or large production; small or large work.	Immersion tanks of suitable capacity. Cleaning and rinsing stages can be of mild steel. Coating stage can be of heavy mild steel or stainless steel.	2-10 mins.	100-600
		Improved paint adhesion	Stampings, castings, forgings, or fabricated sheet metal parts: meter cases; cabinet hardware; etc.; rockets, vehicular sheet metal, bolts and links.	Small, medium or large production; small or large work.	Immersion tanks of suitable capacity. Cleaning and rinsing stages can be of mild steel. Coating stage can be of heavy mild steel or stainless steel.	2-5 mins.	100-600

Brush, spray (hand) or flow processes	Zinc phosphate	Improved paint adhesion	Equipment and other cold-rolled sheet steel products that require re-finishing after repairing, or that have not been previously coated; steel or iron surfaces too large to be treated in normal dip or spray processes.	Large, small and intermittent production; large work.	Ordinary hand applicators such as: a paint-spray gun; an insect sprayer; a hose for flowing the liquid on the work.	2-15 mins.	100-200

FIGURE 9.11 PROTECTIVE COATING CHEMICALS FOR PAINT-BONDING ON ZINC

Spray processes	Zinc phosphate	Improved paint adhesion	Zinc alloy die castings; zinc or cadmium plated sheet or components; hot dip galvanized stock; galvanneal.	Small, medium or large volume; large or small work.	Power spray washer with required number of stages. Cleaning and rinsing stages can be of mild steel. Coating stage can be of heavy mild steel or stainless steel.	7 secs.-2 mins.	75-500
		Improved paint adhesion	Zinc and steel products when these metals are processed in the same bath and equipment.	Small, medium or large volume; large or small work.	Power spray washer with required number of stages. Cleaning and rinsing stages can be of	1-3 mins.	75-500

FIGURE 9.11 PROTECTIVE COATING CHEMICALS FOR PAINT-BONDING ON ZINC (cont.)

Method of Application	Type of Coating	Object of Coating	Typical Metal Products Treated	Scale of Production	Equipment Notes	Coating Time	Coating Wt. Range
					mild steel. Coating stage can be of heavy mild steel or stainless steel.		
	Chromate	Improved paint adhesion and corrosion-resistance	Most types of electro-deposited zinc, zinc die casting alloys, hot-dipped galvanized surfaces and cadmium plate; electronic equipment; ground signal equipment, etc.	Small, medium or large production; large or small work.	Power spray washer with required number of stages. Cleaning and rinsing stages can be of mild steel. Coating stage can be of heavy mild steel or stainless steel.	5-30 secs.	
Dip processes	Zinc phosphate	Improved paint adhesion	Zinc alloy die castings; zinc or cadmium plated sheet or components; hot dip galvanized stock; galvanneal.	Small, medium or large volume; large or small work.	Immersion tanks of suitable capacity. Cleaning and rinsing stages can be of mild steel. Coating stage can be of heavy mild steel or stainless steel.	1-5 mins.	75-500
	Zinc phosphate	Improved paint adhesion	Zinc and steel products when these metals are processed in the same bath and equipment.	Small, medium or large volume; large or small work.	Immersion tanks of suitable capacity. Cleaning and rinsing stages can be of mild steel. Coating stage can be of heavy mild steel or stainless steel.	2-5 mins.	75-500

Dip processes	Chromate	Improved paint adhesion and corrosion-resistance	Most types of electro-deposited zinc, zinc die casting alloys, hot-dipped galvanized surfaces and cadmium plate; electronic equipment; ground signal equipment; etc.	Small, medium or large production; large or small work.	Immersion tanks of suitable capacity. Cleaning and rinsing stages can be of mild steel. Coating stage can be of heavy mild steel or stainless steel.	5-30 secs.	
Brush, spray (hand) or flow processes	Zinc phosphate	Improved paint adhesion	Signs, siding, roofing, galvanized truck bodies, corrugated structures, etc.	Large, small and intermittent production.	Ordinary hand applicators such as: a brush, paint-sprayer, etc.	2-5 mins.	200-600
		Improved paint adhesion	Recommended for unreactive zinc surfaces.	Large, small and intermittent production.	Ordinary hand applicators such as: a brush, paint-sprayer, etc.	2-5 mins.	200-600

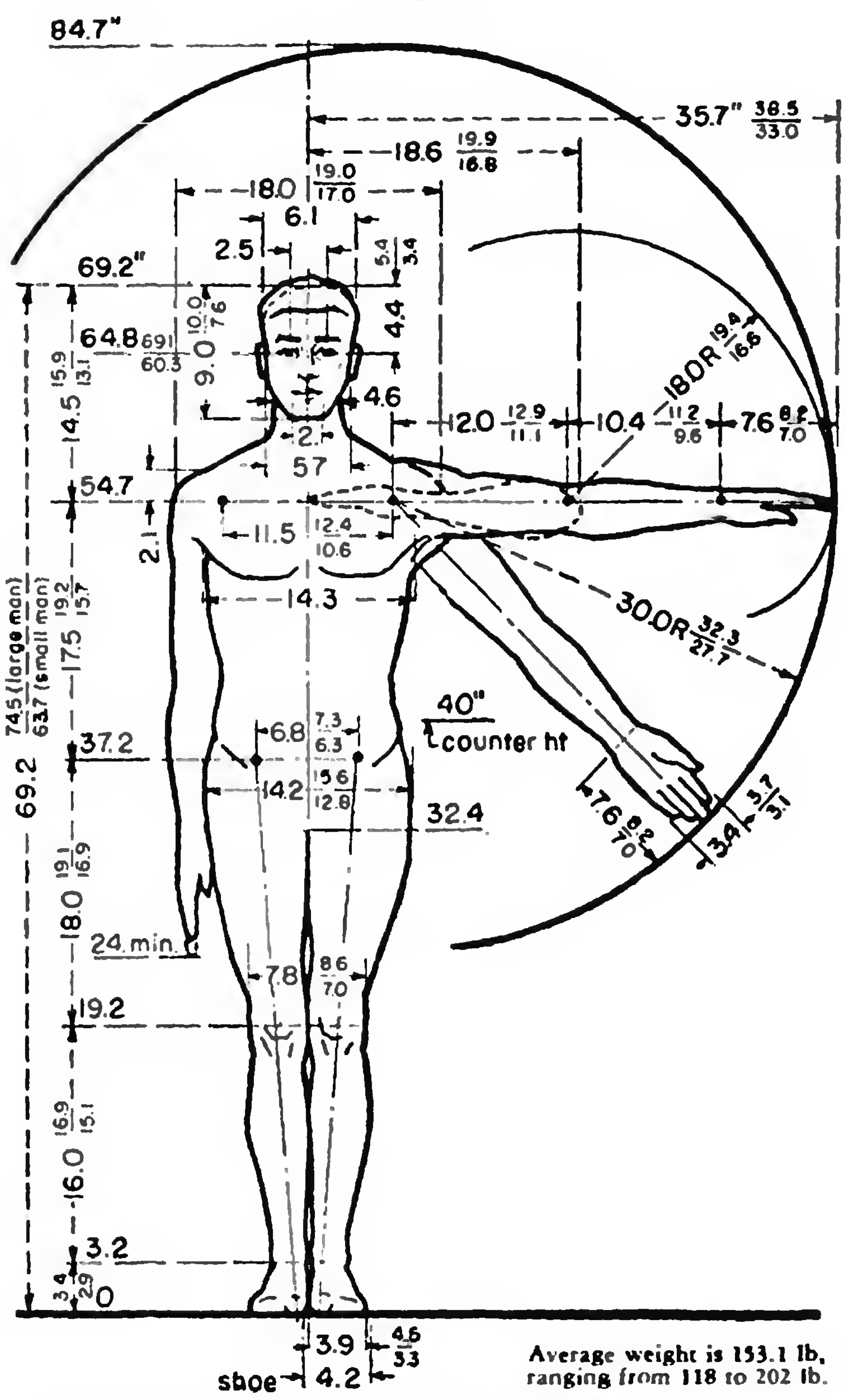
FIGURE 9.12 AVERAGE NUMBER OF MAN-HOURS

	Week	Month	Year[1]	Year[2]
8 Hour Day @ 5/wk	40	172	2160	-
9 Hour Day @ 5/wk	45	194	2340	-
10 Hour Day @ 5/wk	50	215	2600	-
32 Hour Week	-	138	1665	1625
40 Hour Week	-	172	2160	2030
42 Hour Week	-	181	2185	2135
44 Hour Week	-	189	2290	2235
45 Hour Week	-	194	2340	2290
48 Hour Week	-	213	2500	2440
50 Hour Week	-	215	2600	2540
52 Hour Week	-	224	2700	2640

[1]No holidays.
[2]Six holidays.

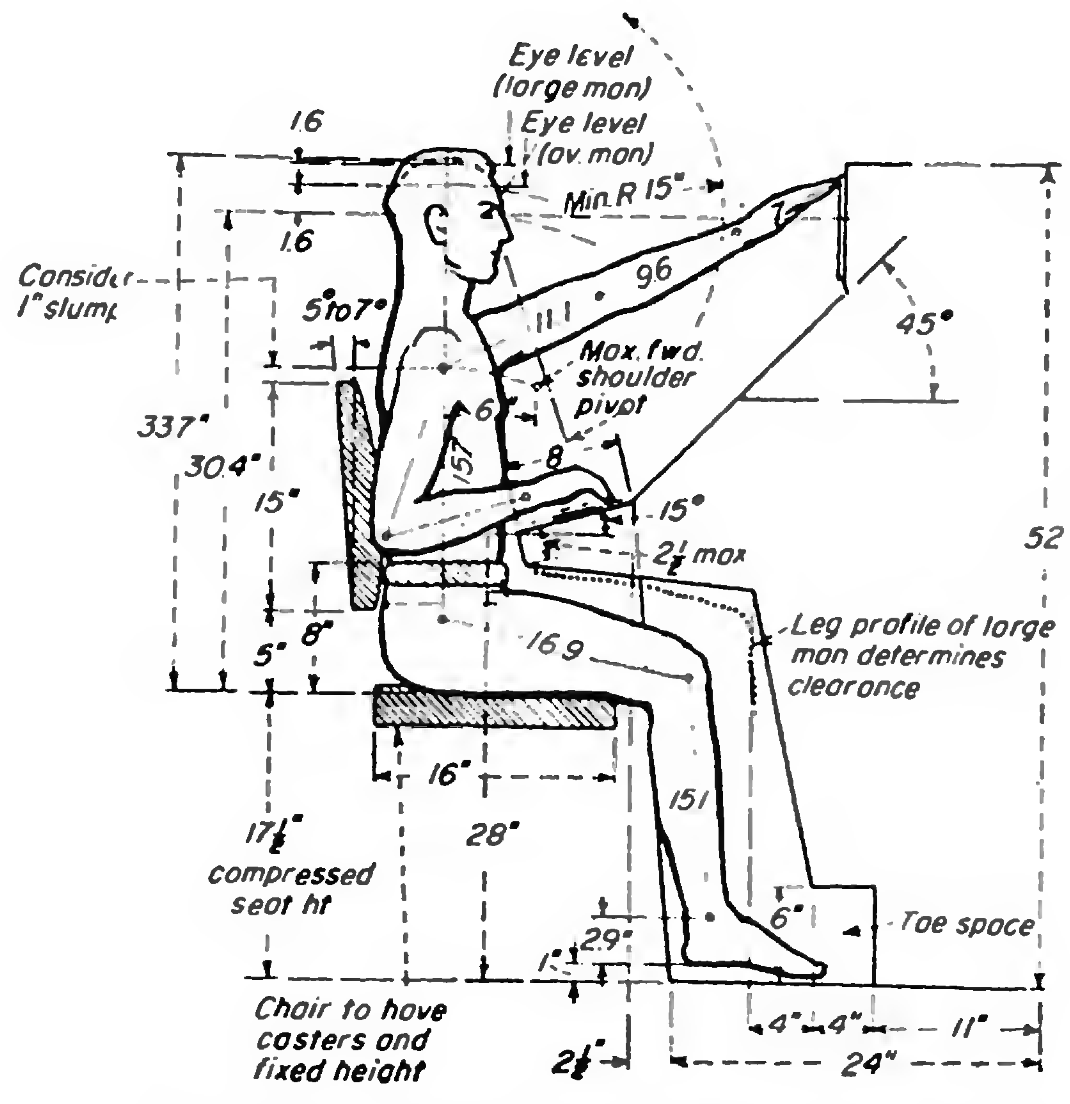
FIGURE 9.13 HUMAN DIMENSIONS

Fig. 1



Human dimensions of the average adult male based on the 2-1/2 to 97-1/2 per cent range of measured subjects.

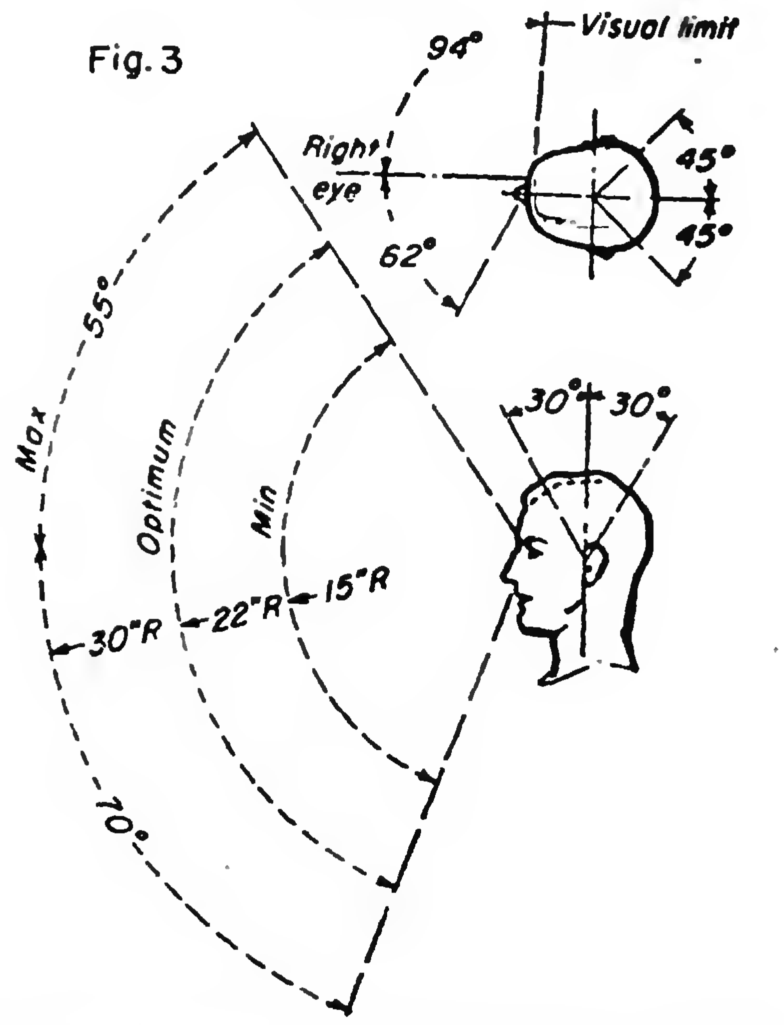
Fig. 2



Seating is dependent on reach, vision, and work load on the operator. This drawing is based on the small man which accomodates the reach limitations of 95 per cent of all men.

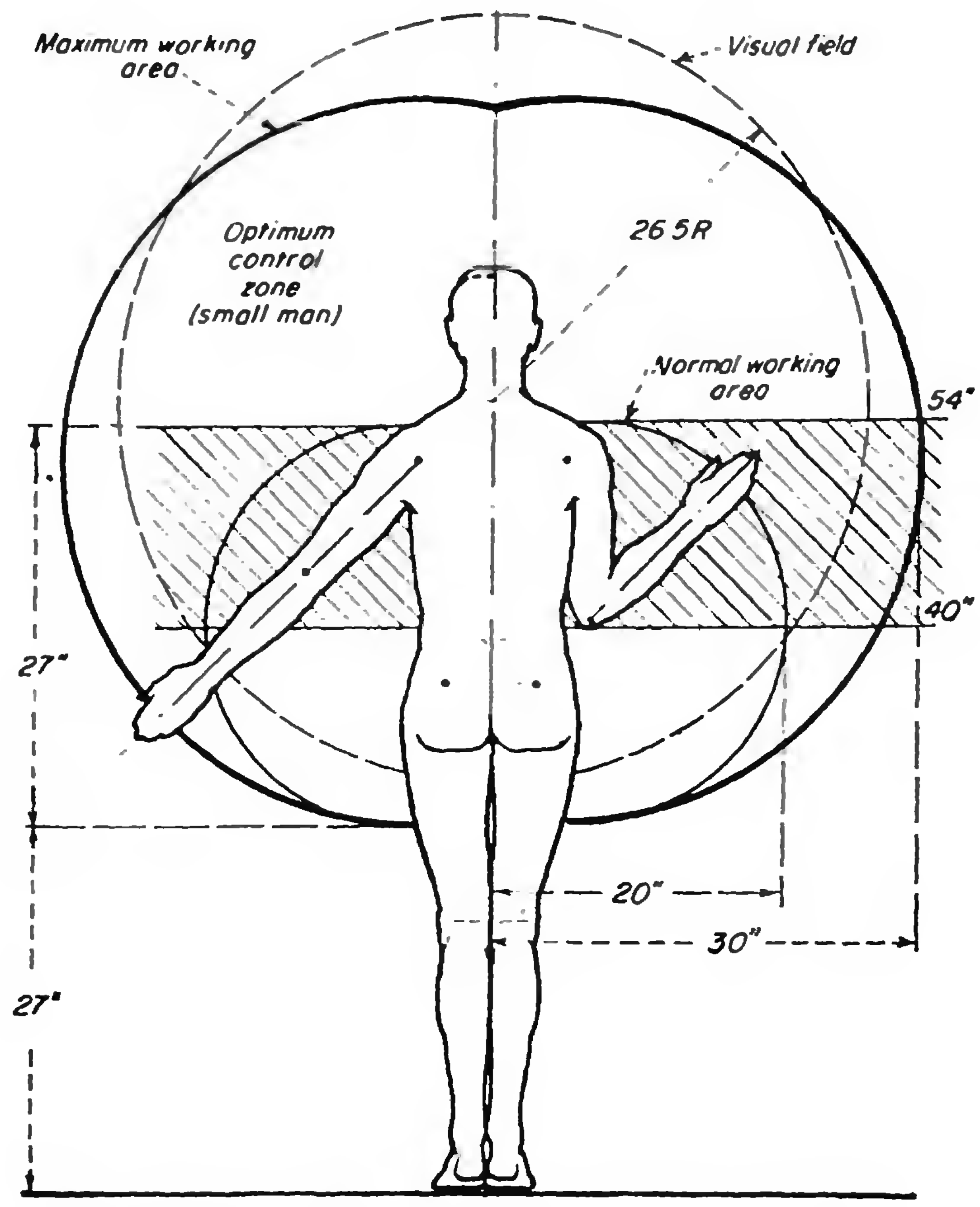
FIGURE 9.13 HUMAN DIMENSIONS (cont.)

Fig. 3



Visibility studies must include considerations of size, color, lighting, and purpose of the equipment. Where concentrated attention will be required, effective visual areas are considerably reduced.

Fig. 4



Standing operator with most effective areas for controls cross hatched. Drawing is based on small man (2-1/2 percentile).

Fig. 5

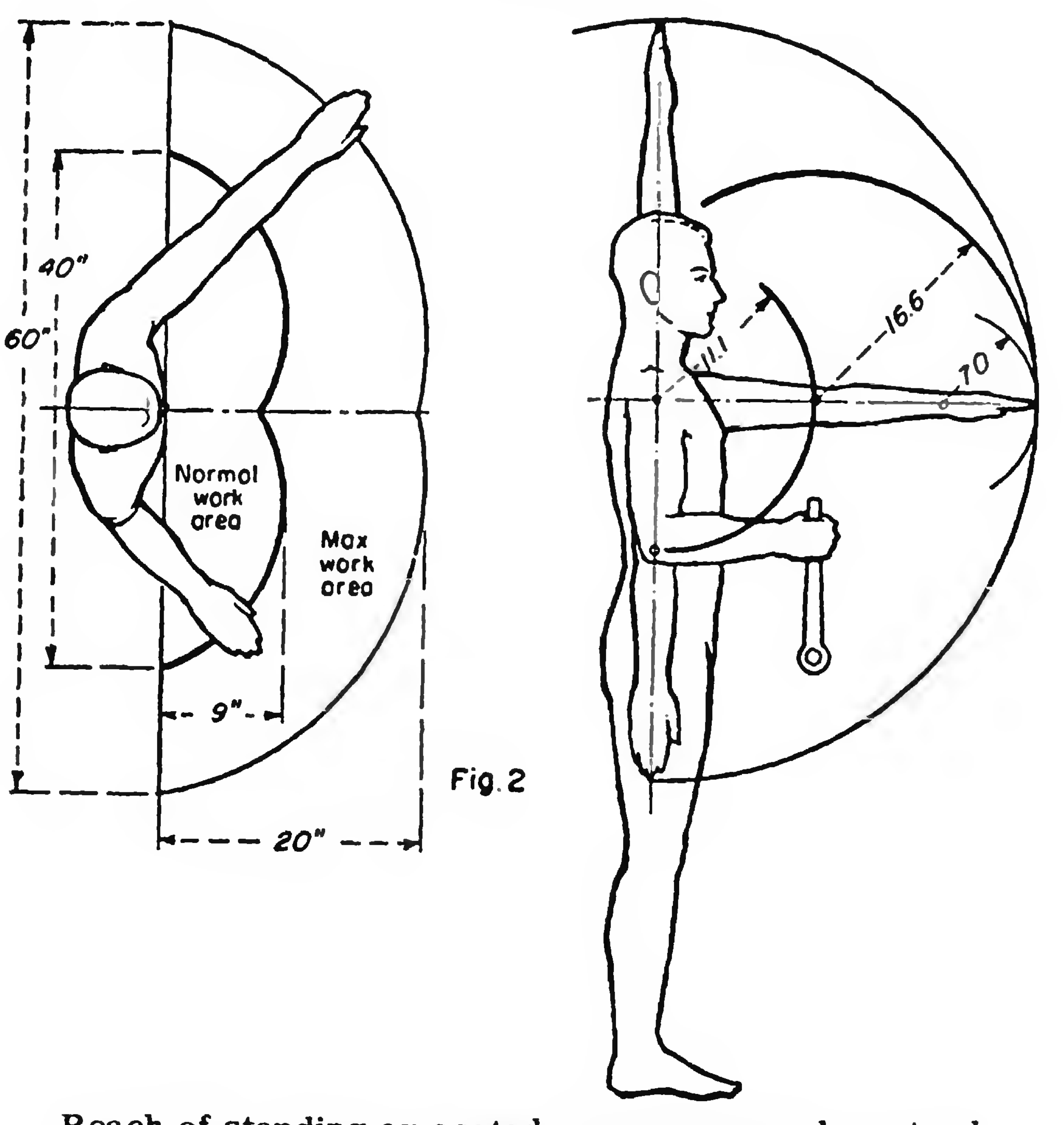
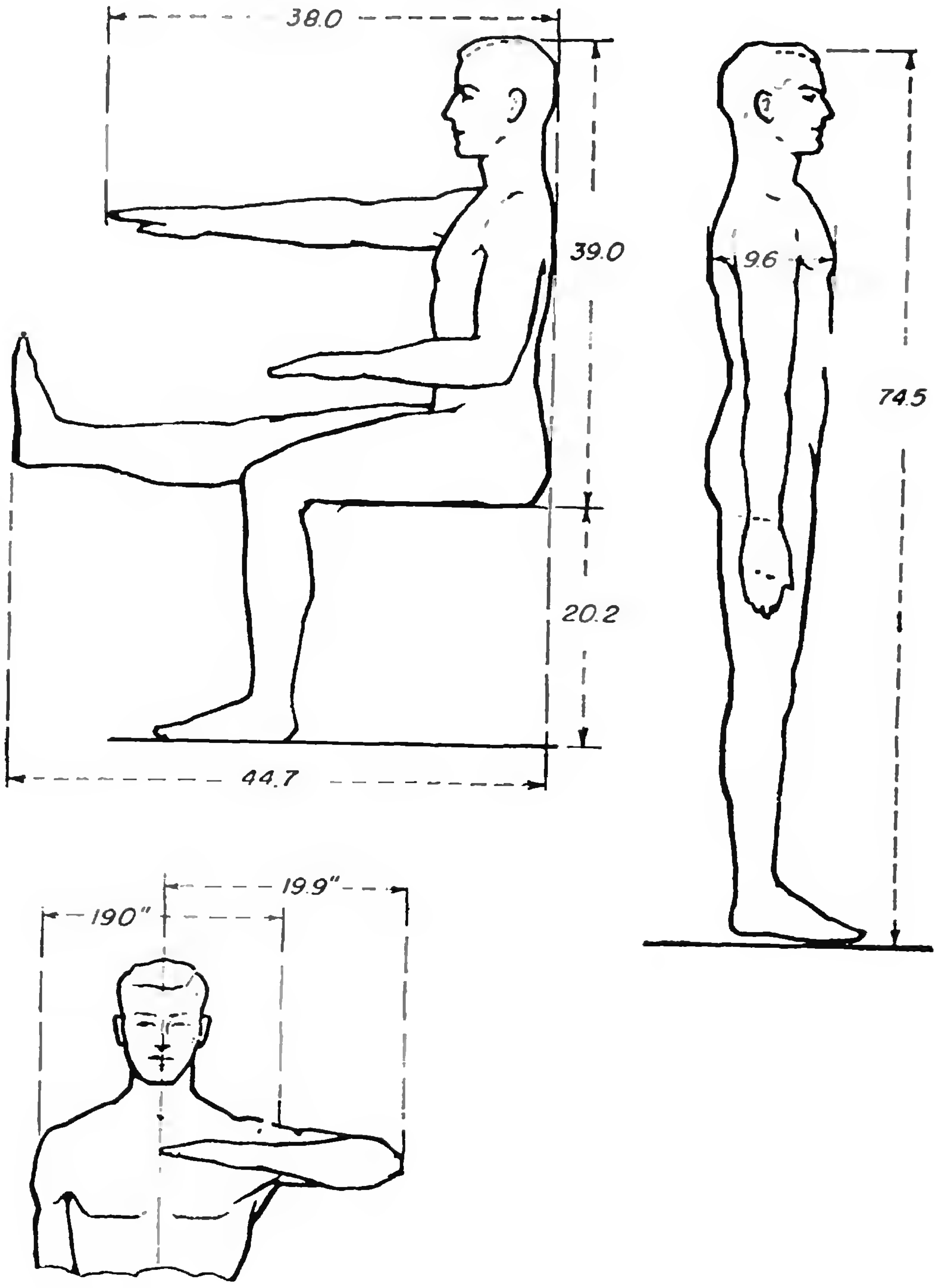


Fig. 2

Reach of standing or seated operators may be extended beyond these limits by lateral motion or pivoting at the waist. Drawings are based on the small man (2-1/2 percentile), body rigid and stationary.

FIGURE 9.13 HUMAN DIMENSIONS (cont.)

Fig. 6



Enclosed spaces have psychological as well as antropometric hazards. Space must be provided for alternate body and leg positions to relieve cramped muscles. Drawings are based on large man (97-1/2 percentile).

FIGURE 9.14 PHONETIC ALPHABETS

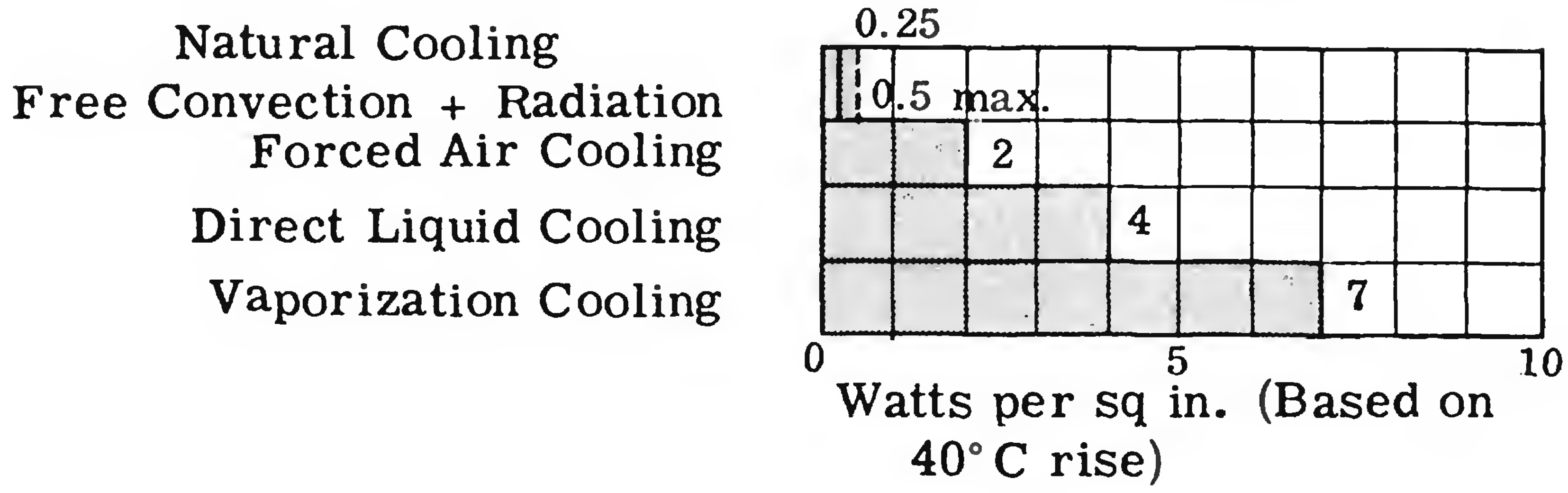
ICAO (International Civil Aviation Organization)

A Alpha	G Golf	N November	T Tango
B Bravo	H Hotel	O Oscar	U Uniform
C Charlie	I India	P Papa	V Victor
D Delta	J Juliet	Q Quebec	W Whiskey
E Echo	K Kilo	R Romeo	X Xray
F Foxtrot	L Lima	S Sierra	Y Yankee
	M Mike		Z Zulu

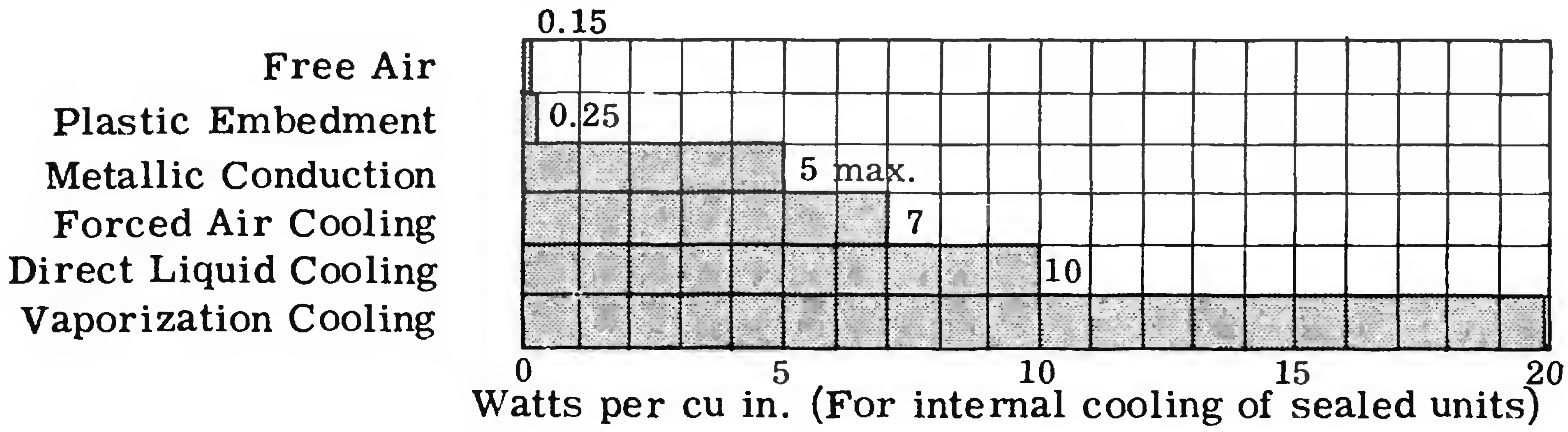
US Armed Services

A Able	G George	N Nan	T Tare
B Baker	H Howe	O Oboe	U Uncle
C Charlie	I Item	P Peter	V Victor
D Dog	J Jig	Q Queen	W William
E Easy	K King	R Roger	X Xray
F Fox	L Love	S Sugar	Y Yoke
	M Mike		Z Zebra

FIGURE 9.15 HEAT REMOVAL FROM ELECTRONIC EQUIPMENT



A. SURFACE MOUNTING



B. VOLUME MOUNTING

Approximate amount of heat removable by the techniques indicated for different power densities of the equipment mounted on a surface area (A) or in a volume (B)

LAPLACE TRANSFORMATION

Conversion from time domain to frequency domain is made by the Laplace transform, and conversely, from frequency domain to time domain by inverse transformation. The Laplace transform is defined by

Eq. 1 $$F(s) \triangleq \mathcal{L}(t)$$

where $F(s)$ is a function of s
s equals $j\omega$, for steady-state conditions
$\mathcal{L}$ means the transform integral, and
$f(t)$ is a function of time.

Eq. 2 $$F(s) = \mathcal{L}f(t) = \int_0^\infty f(t)e^{-st}\,dt$$

The exponential decay function, $e^{-\alpha t}$, occurs frequently in nature. The transform here is

Eq. 3 $$F(s) = \int_0^\infty e^{-\alpha t}\, e^{-st}\,dt = \int_0^\infty e^{-(s+\alpha)t}dt$$

$$= \left[-\frac{1}{s+\alpha}e^{-(s+\alpha)t}\right]_{t=\infty} - \left[-\frac{1}{s+\alpha}e^{-(s+\alpha)t}\right]_{t=0}$$

$$= 0 + \frac{1}{s+\alpha} = \frac{1}{s+\alpha}$$

The transform can then be set up in a table.

FIGURE 9.15 HEAT REMOVAL FROM ELECTRIC EQUIPMENT (cont.)

In the case of critical damping, C = i, the characteristic equation is

Eq. 4 $$F(s) = \frac{1}{(s + \omega_o C)(s + \omega_o C)} \quad \text{and} \quad f(t) = te^{-\omega_o t}$$

See Fig. 10.58

In dealing with a transfer function in terms of F(s), the time domain input signal, f(t), must also be converted to its F(s). For instance, a unit step change input has f(t) - 1. Converting by the Laplace transform gives F(s) = s.

FIGURE 9.16 TRANSFORM PAIRS

No.	F(s)	f(t) $0 \leqslant t$
1	$\frac{1}{s}$	1, or unit step function u(t)at t = 0
2	$\frac{1}{s^2}$	t
3	$\frac{1}{s + \alpha}$	$e^{-\alpha t}$
4	$\frac{\omega_o}{s^2 + \omega_o^2}$	$\sin \omega_o t$
5	$\frac{s}{s^2 + \omega_o^2}$	$\cos \omega_o t$
6	1	unit impulse at t = 0
7	$\frac{s + \omega_o}{s^2 + \beta^2}$	$\frac{1}{\beta}(\omega_o + \beta^2)^{\frac{1}{2}} \sin(\beta t + \psi)$ $\psi = \tan^{-1} \beta/\omega_o$
8	$\frac{1}{s(s^2 + \beta^2)}$	$\frac{1}{\beta^2}(1 - \cos \beta t)$
9	$\frac{1}{(s + \alpha)^2 + \beta^2}$	$\frac{1}{\beta} e^{-\alpha t} \sin \beta t$
10	$\frac{s + \omega_o}{(s + \alpha)^2 + \beta^2}$	$\frac{1}{\beta}[(\omega_o - \alpha)^2 + \beta^2]^{\frac{1}{2}} e^{-\alpha t} \sin(\beta t + \psi)$ $\psi = \tan^{-1} \beta/(\omega_o - \alpha)$
11	$\frac{s + \alpha}{(s + \alpha)^2 + \beta^2}$	$e^{-\alpha t} \cos \beta t$
12	$\frac{1}{s[(s + \alpha)^2 + \beta^2]}$	$\frac{1}{\beta_o^2} + \frac{1}{\beta\beta_o} e^{-\alpha t} \sin(\beta t - \psi)$ $\psi = \tan^{-1} \beta/-\alpha$ $\beta_o^2 = \alpha^2 + \beta^2$

FIGURE 9.16 TRANSFORM PAIRS (cont.)

13	$\dfrac{s + \omega_o}{s\left[(s + \alpha)^2 + \beta^2\right]}$	$\dfrac{\omega_o}{\beta_o^2} + \dfrac{1}{\beta\beta_o}\left[(\omega_o - \alpha)^2 + \beta^2\right]^{\frac{1}{2}} e^{-\alpha t} \sin(\beta t + \psi)$ $\psi = \tan^{-1} \beta/(\omega_o - \alpha) - \tan^{-1} \beta/-\alpha$ $\beta_o^2 = \alpha^2 + \beta^2$
14	$\dfrac{1}{(s + \alpha)^n}$	$\dfrac{1}{(n - 1)!} t^{n-1} e^{-at}$

FIGURE 9.17 CONSTRUCTION OF BODE DIAGRAMS

The advantages of Bode diagrams in the frequency domain are:

Transfer functions can be approximated by straight line segments. The segments are asymptotic to the actual response.

The diagram can be constructed by inspection of the factored form of the transfer function.

The overall function can be obtained by adding separately the magnitudes and the phase shifts of the individual functions.

The magnitudes are plotted on log-log graph paper, and the phase shifts on linear coordinates against log frequency.

Consider the term $(1 + j\omega T)$. The magnitude and phase shift at any ω can be found by trigonometric solution of a right triangle. Magnitude equals

$$[1^2 + (\omega T)^2]^{1/2} \text{ and}$$

the phase shift equals

$$\arctan \frac{\omega T}{1}$$

When ωT equals unity magnitude equals 1.414 (3 db) and the phase shift equals 45 deg. The frequency at which ωT equals unity is called the "break" frequency.

For simplicity, the term may be approximated by two line segments that are asymptotes of the actual magnitude. Below the break frequency the line is horizontal; above, it rises at 20 db/decade. A decade is a ten to one ratio of frequency. The phase shift is zero deg at ω equals zero, plus 45 deg at the break frequency, and plus 90 deg at infinite ω.

Terms of the form

$$\frac{1}{1 + j\omega T}$$

can be handled in a similar matter, but are inverse. That is, the phase shifts are negative and the magnitude falls off at minus 20 db/decade. Plotted in Figure A are the individual magnitudes and phase shifts of the terms in transfer function:

$$KG = \frac{K(1 + j\omega T_2)}{j\omega(1 + j\omega T_1)} \quad \text{where} \quad T_1 > T_2$$

The phase shift of the overall transfer function of Figure A approaches minus 90 deg at high ω. Therefore, the closed loop system cannot be unstable. However,

FIGURE 9.17 CONSTRUCTION OF BODE DIAGRAMS (cont.)

added transfer functions containing $j\omega$ terms in the denominator may cause instability.

Since transfer functions are represented by straight line segments, the correcting functions can also be represented this way. Segments designating corrective networks or devices, or shifts to indicate change gain, are added to the overall transfer function so that the modified function is stable. The frequency range, ω_x to ω_y, in which the correction is required, can be easily determined from the plot.

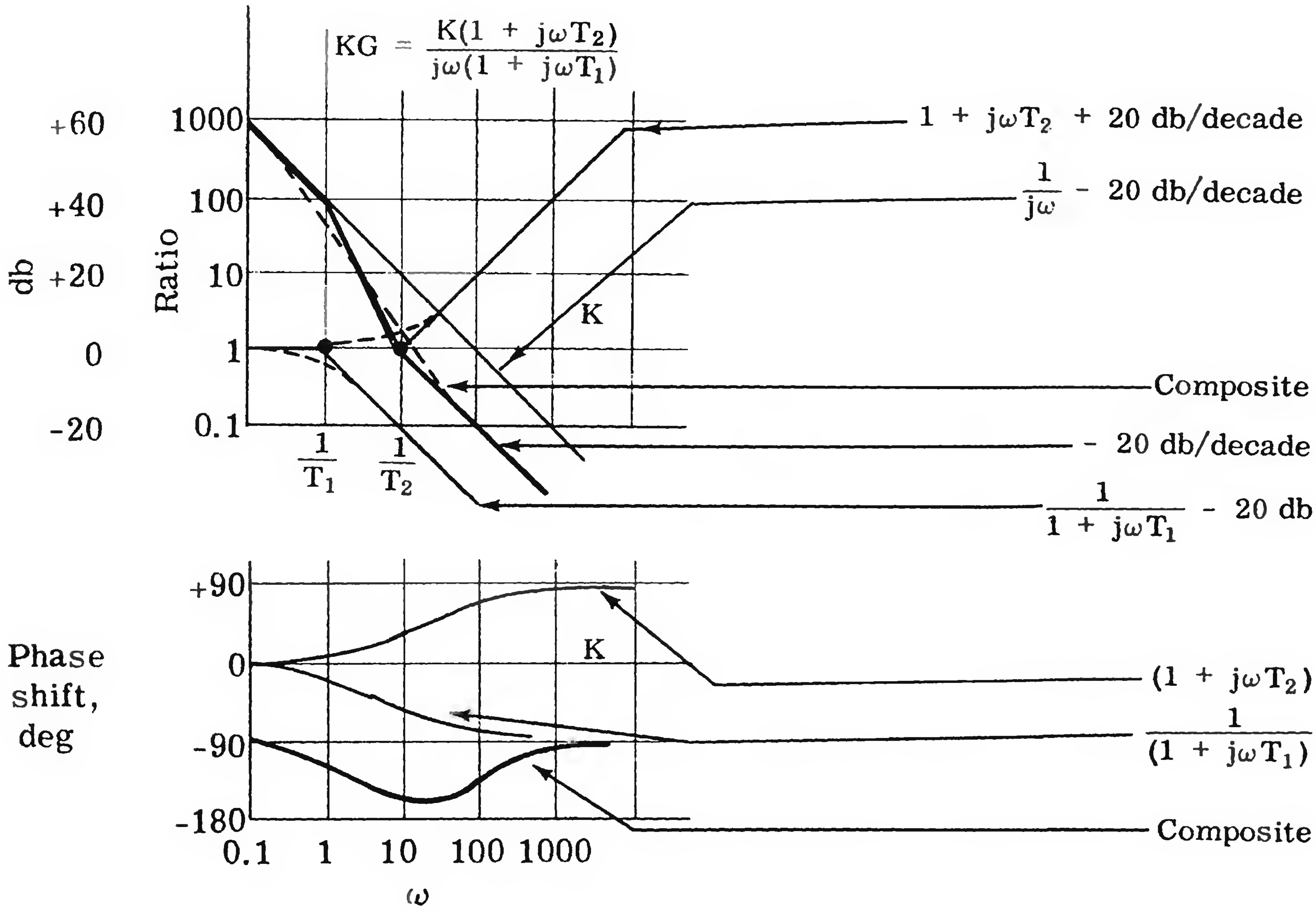


Fig. A. Bode diagram of the open-loop transfer function, KG. shows magnitude and phase shift of the individual terms in the function. Adding the individual line segments produces the composite response for KG (heavy lines). Solid lines indicate approximate (asymp totic) response of the terms while the dashed lines represent the true response.

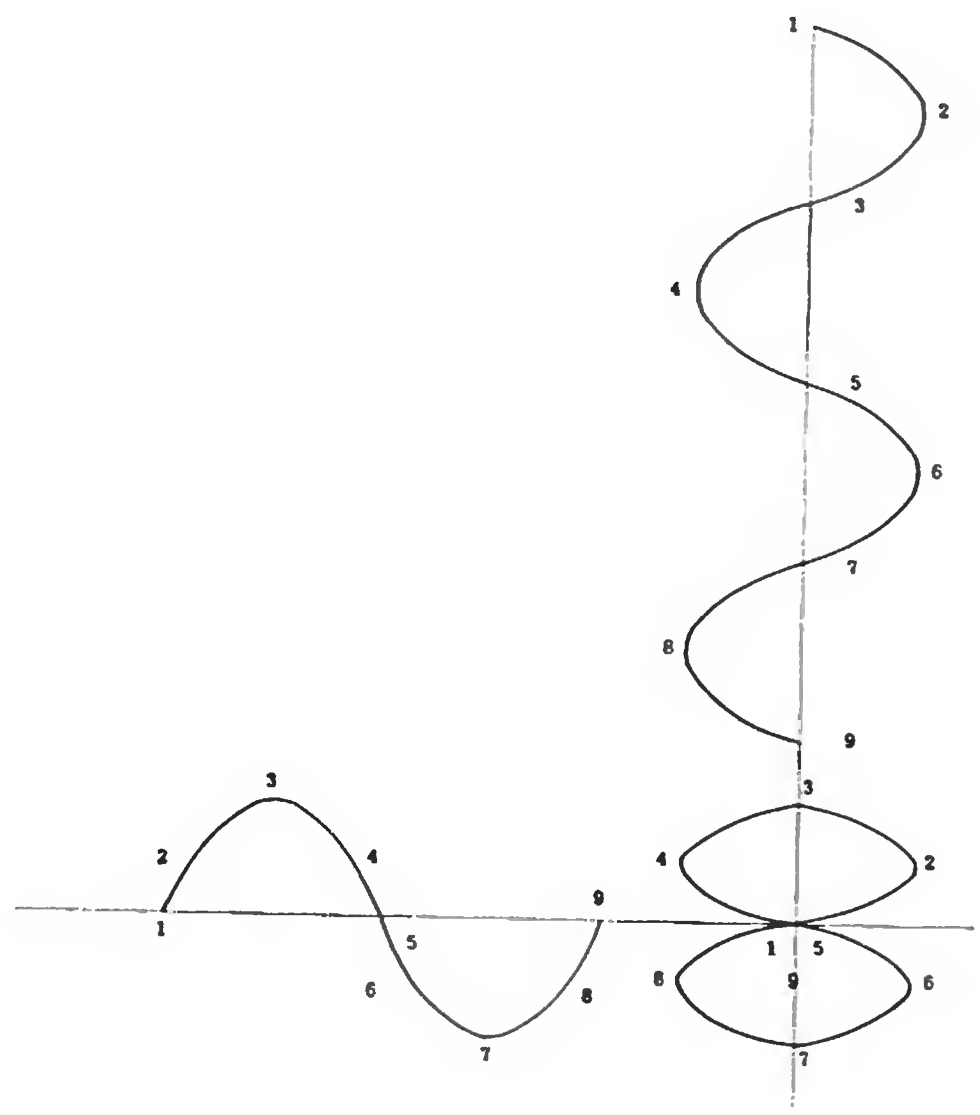
FIGURE 9.18 LISSAJOUS FIGURES

A characteristic and useful portrayal of the combination of two sine saves. When two sine waves, varying about axes at right angles, are combined the resultant figure is no longer a sine wave but varies with the relative timephase of the waves and with their relative frequency. For example, if the waves have the same frequency the resultant is a straight line when they are in time phase (or 180° out of phase) and is an ellipse for all other values of phase position. For equal amplitudes

FIGURE 9.18 LISSAJOUS FIGURES (cont.)

of the original waves and 90° phase the ellipse is the special case of the circle. If the frequencies of the two waves are not the same the resultant becomes more complicated but gives a definite pattern whenever the frequencies are in the ratio of whole numbers to one another. The figure shows a graphical construction for a frequency ratio of 4:3.

Such figures are obtained when the resultant motion of two simple harmonic motions at right angles to each other is examined. The figures can be produced in a cathode-ray tube by supplying each deflection-circuit with harmonically-related voltages. The figures are used thus for phase and frequency measurements.



MISCELLANEOUS DATA

Mechanical amplification of structural elements

Conventional structures	15-150
Miniature tubes	175-500
Subminiature tubes	800-1400
Packaging chassis	30-200
Gyros	50-300
Control sys. servos	10-50

Heat absorbing capacity of air

Altitude	Cap. for the same volume of air at S.L., %
S.L.	100
20000	50
40	25
60	10
80	3

ACCELERATION

The distance traveled for a given velocity change and acceleration

Velocity Change	1g	10 g	40 g	100 g
60 mph	120 ft	12 ft	3 ft	1 ft
Mach 1	3.6 mi	0.4 mi	470 ft	188 ft
Mach 5	89 mi	8.9 mi	2.2 mi	0.9 mi
Mach 10	357 mi	35.7 mi	8.9 mi	3.6 mi
Mach 20	1430 mi	143 mi	35.7 mi	14.3 mi
Mach 35	4370 mi	437 mi	109 mi	44 mi

MISCELLANEOUS EQUATIONS

Eq. 9.1 Force

$$F = m\ a = \frac{w}{g} a$$

Eq. 9.2 Power Spectral Density

$$PSD = \frac{g^2}{\Delta f}$$

$$\text{and } g = \sqrt{\frac{1}{2} \Sigma A}$$

PSD = intensity for 1 cycle of band width
Δf = band width, cps
g = rms gravity
A = max. amplitude of acceleration for each frequency in the band width

Eg. 9.3 Maximum Scanning Rate for Vibration Testing

$$S.R. = \pi \frac{f^2}{Q^2}$$

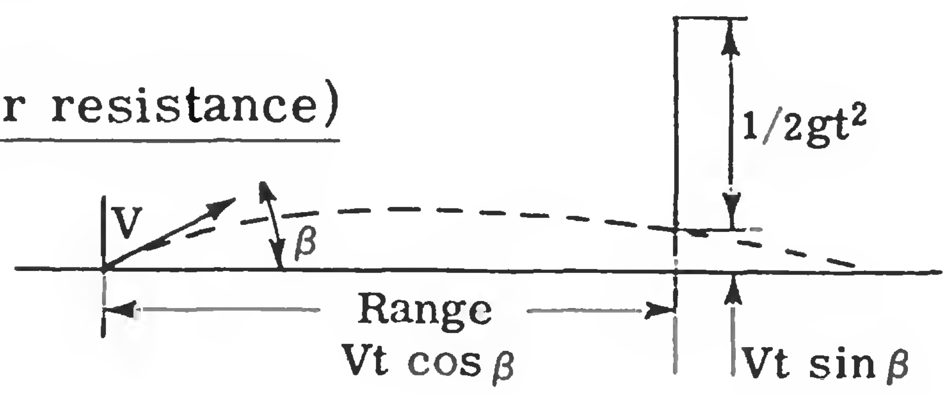
Eq. 9.4 Root Mean Square Amplitude

$$RMS\ \ X = \frac{A}{\sqrt{2}}\ ; \text{ double amplitude } = \sqrt{2}\, A$$

Eq. 9.5 Trajectory of a Projectile (neglecting air resistance)

$$\text{Range} = Vt \cos \beta$$

$$\text{Altitude} = Vt \sin \beta - \frac{1}{2} gt^2$$



Eq. 9.6 Velocity in General

Linear	Angular
$s = f\ (t),$	$\theta = f\ (t),$
$v = \frac{ds}{dt},$	$\omega = \frac{d\theta}{dt},$
$a = \frac{dv}{dt} = \frac{d^2s}{dt^2},$	$\alpha = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2},$
$a\ ds = v\ dv,$	$\alpha\ d\theta = \omega\ d\omega,$
	$\alpha = \frac{a_t}{r},$
	$\omega^2 = \frac{a_n}{r}.$

MISCELLANEOUS EQUATIONS (cont.)

Eq. 9.7 Velocity Uniform

Linear | Angular

Distance = (velocity) X (time)

$s = vt,$ $\theta = \omega t.$

Since there is no change in velocity the linear or tangential acceleration will be zero.

$a = a_t = 0,$ $\alpha = 0,$

$v = \frac{2\pi rN}{60} = \omega r,$ $\omega = \frac{2\pi N}{60} = \frac{v}{r}$

$a_n = \frac{v^2}{r}$ $a_n = r\omega^2.$

Eq. 9.8 Velocity, Variable - Uniform Acceleration

Linear | Angular

Final velocity = Initial velocity + (acceleration) X (Time)

$v_2 = v_1 + at,$ $\omega_2 = \omega_1 + \alpha t.$

Distance = (Initial velocity) X (time) + (1/2) (Acceleration) X (time)^2.

$s = v_1 t + \frac{1}{2} at^2,$ $\theta = \omega_1 t + \frac{1}{2} \alpha t^2.$

(Final velocity)^2 = (Initial Velocity)^2 + 2 (Acceleration) X (distance)

$v_2^2 = v_1^2 + 2as,$ $\omega_2^2 = \omega_1^2 + 2\alpha\theta.$

SECTION 10
GLOSSARY

Å

(See Angstrom Unit)

AAM (Air-to-Air Missile)

(See Missile, Air-to-Air; Missile, Guided; Model Designation)

Aero THermODYnamic Duct

Athoyd (See Ramjet)

AFC

(See Automatic Frequency Control)

AGC

(See Automatic Gain Control)

AGM (Air-to-Ground Missile)

(See Missile, Air-to-Ground; Missile, Guided; Model Designation)

AI

Air Intercept Radar (See Radar, Air Intercept)

AIGS

All-Inertial Guidance System

AM

(See Modulation, Amplitude)

APGC

Air Proving Ground Command, Eglin Air Force Base, Valparaiso, Florida. The work of the Air Proving Ground Command is related to that of ARDC in that it determines the operational suitability of aircraft, materiel, and equipment used or proposed for use by the Air Force, except for atomic weapons and their specialized equipment.

APS

(See Accessory Power Supply)

APU

(See Accessory Power Supply; Auxiliary Power Unit)

AQL

(See Acceptable Quality Level)

ARL

(See Acceptable Reliability Level)

ASCOP

Applied Science Corporation of Princeton. A commercial producer of data acquisition and reduction equipment.

ASM (Air-to-Surface Missile)

(See Missile, Air-to-Ground; Missile, Guided; Model Designation)

AUM (Air-to-Underwater Missile)

(See Model Designation; Missile, Air-to-Ground)

Aberration

The phenomenon caused by rotation of the earth in its orbit which is sufficient to cause the light from the stars to appear to shift forward. For those stars at right angles to the direction of the earth's travel the maximum effect is 20.5 sec of arc.

Abortion

(1) A kill which prevents enemy targets from proceeding with their tactical mission.

(2) An unplanned termination of a missile mission.

Absolute Velocity

(See Velocity, Absolute)

Absorption

(1) The process whereby the total number of particles emerging from a body is reduced relative to the number entering as a result of interaction of the particles with the body.

(2) The process whereby the kinetic energy of a particle is reduced while traversing a body. This loss of kinetic energy (of corpuscular radiation) is also referred to as moderation, slowing, or stopping.

(3) The process whereby some or all of the energy of electromagnetic radiation is transferred to the body on which it is incident or which it traverses.

Acceleration

The time rate of change of velocity in either speed or direction.

Acoustomotive Pressure

(See Sound (Acoustomotive) Pressure)

Acceleration, Amplitude

(See Amplitude Acceleration)

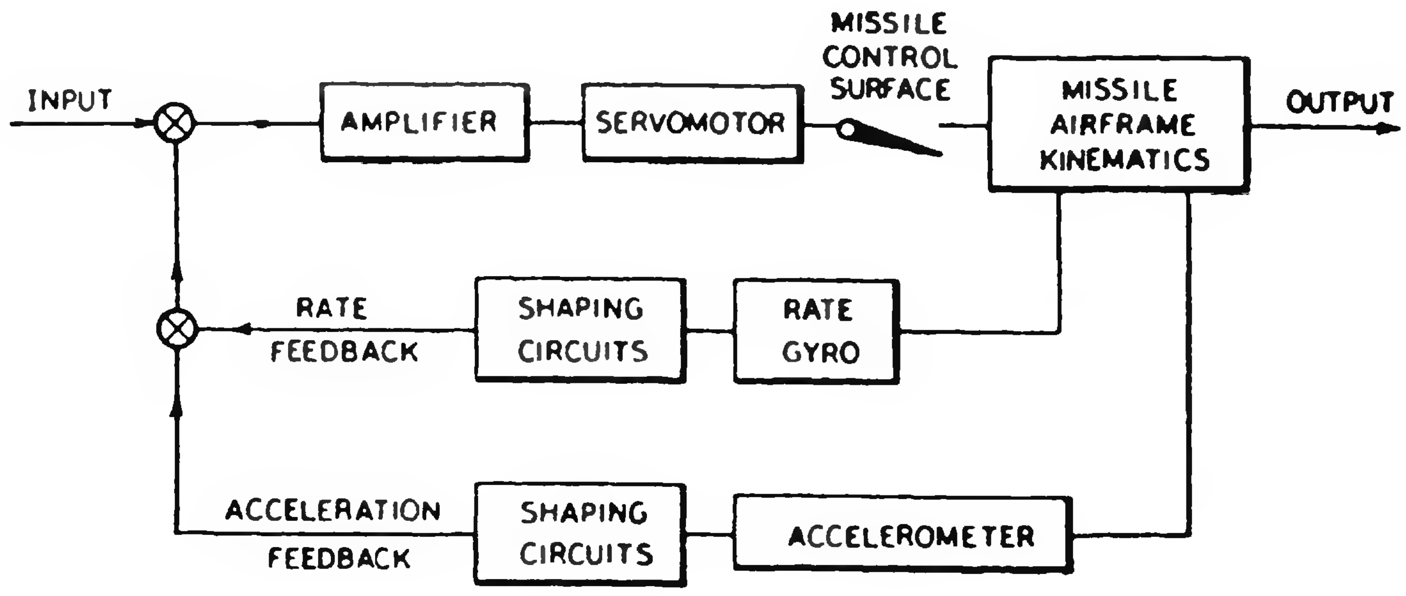
Acceleration Blowout

Inadvertent loss of combustion in a turbojet engine incident to an attempted acceleration and overrich fuel mixture. Does not normally apply to engines using an acceleration control. Also termed rich extinction or flameout.

Acceleration Feedback

A sensing system for control of a missile. Properly located accelerometers are used to sense body accelerations which are fed into the control system for correction of the motion. Usually used to eliminate effects of body bending or to maintain angles of attack at predetermined values. (See Fig. 10.1)

FIGURE 10.1 SIMPLIFIED BLOCK DIAGRAM OF AUTOPILOT SHOWING ACCELERATION FEEDBACK



Acceleration Spectral Density (Power Spectral Density)

A measure of the energy distribution in a complex wave. (See Eq. 9.2, p. 386)

Accelerations, Phantom

(See Phantom Accelerations)

Accelerator, Linear

(See Linear Accelerator)

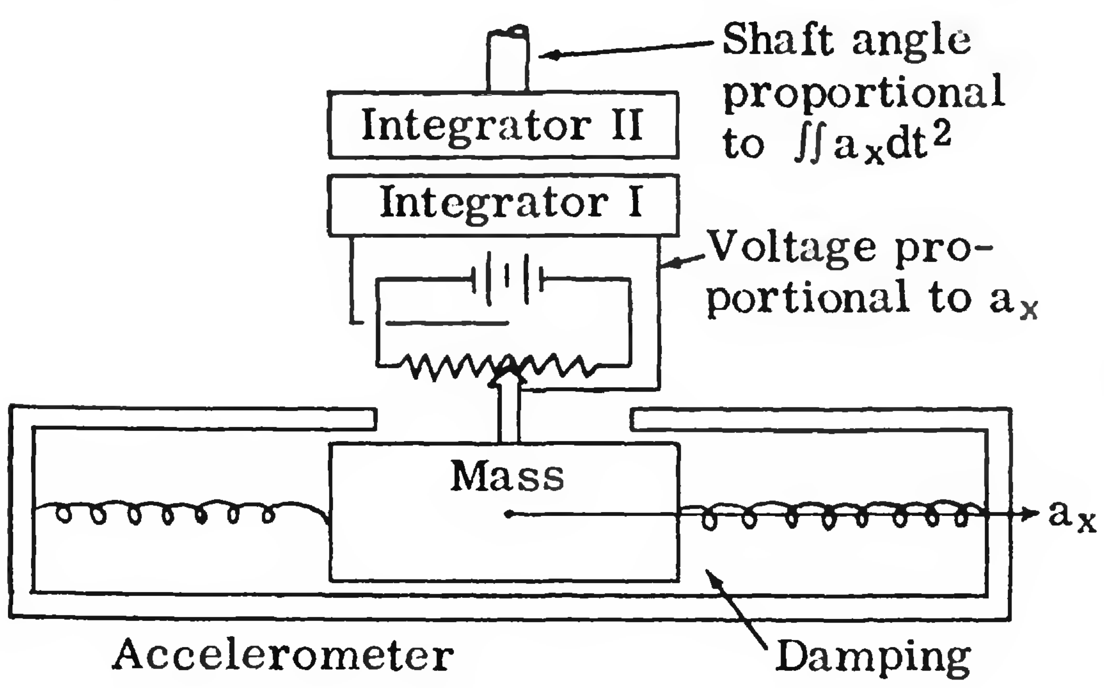
Accelerometer

A device used to measure acceleration, which, when integrated, will yield velocities or displacements (depending on the particular sensing elements and related networks). Accelerometers may sense angular or linear accelerations.

Accelerometer, Integrating

A device whose output signals are proportional to vehicle velocity or distance traveled (depending on number of integrations) instead of acceleration. (See Fig. 10.2)

FIGURE 10.2 SCHEMATIC OF A NAVIGATIONAL ACCELEROMETER & INTEGRATOR



The accelerometer output is integrated twice to determine the distance the missile travels.

Accelerometer Matching

A method of aligning two remote reference systems; e.g., stabilized platforms, by comparing the outputs of identically oriented accelerometers while the two systems are experiencing the same motions.

Accelerometer, Pendulous Gyroscope

An instrument in which the force generator is a gyroscope element.

Acceptable Quality Level (AQL)

A nominal value expressed in terms of per cent defective or defects per hundred units specified for a given group of defects of a product. It is a measure of quality or the fraction defective which will be accepted some preassigned percentage of the time, by a sampling plan.

Note: Sampling plans may be indexed by other points on the curve such as Lot Tolerance Fraction Defective.

(See Operating Characteristic Curve for Acceptance Sampling Plan (OC Curve).

Acceptable Reliability Level (ARL)

The required level of reliability for a part, system, device, etc. It may be expressed in a variety of terms, e.g., number of failures allowable in 1000 hours of operating life.

Acceptance Tests

Tests to determine conformance to design or specifications as a basis for acceptance. When specially designed they may apply to parts, equipments or systems.

Accessory

A supplementary device used in conjunction with an item of equipment or a system, contributing to the effectiveness

thereof without extending or varying the basic function of the equipment, e.g., recording camera attachment, emergency power supply.

Accessory Power Supply (APS)

A self-powered device used to supply electrical and/or hydraulic power to accessory or other auxiliary equipment carried in a missile or aircraft. The same as Auxiliary Power Supply (APS); Auxiliary Power Unit (APU); or Accessory Power Unit (APU).

Accumulator

In computer applications, a device which stores a number and which, on receipt of another number, adds it to the number already stored and stores the sum.

Accuracy in Measurement

The degree of correctness with which a method of measuring yields the "true" value of a measured quantity. It is usually expressed in terms of error, the units being those of the measured quantity or the ratio (or percent) of the error to the full scale value or to the actual value. e.g., 5000 miles $\pm$ 5 miles or $\pm$ 0.1%.

Acoustical System

A system adapted for the transmission of sound and consisting of one or all of the following acoustical elements: acoustical resistance, inertance and acoustical capacitance.

Acoustic Speed (Sonic Speed)

The speed at which sound waves and small pressure disturbances are propagated in a fluid. (See Sonic Speed). (Also Eq. 7.1.7, p. 276 and Fig. 2.8, p. 40)

Acquisition Radar

(See Radar, Acquisition)

Activator, Inertial

A mechanical device employing springs that absorb energy from a velocity change and releases this energy to activate a circuit.

Active Filter

(See Filter, Active)

Adaptation Kit

The devices needed to install and service a special component or system (e.g., warhead) in a missile. Includes structural fittings, fuze, safety and arming mechanism and test circuitry.

Adder

In computer applications, a device which can form the sum of two or more numbers or quantities.

Address

In computer applications, an expression, usually numerical, which designates a particular location in a storage or memory device, or other source or destination information.

Adiabatic Efficiency

The degree to which a change in state of a gas approaches an adiabatic (no change in energy) process.

Admittance

The reciprocal of impedance.

Aerodynamic Coefficients

A system of non-dimensional coefficients used in aerodynamics. The system permits extrapolation of model data to full-scale designs, development of tests, etc. (See Eq. 5.1, p. 212)

Aerodynamic Damping

Resistance to motion of a missile caused by aerodynamic forces acting on the aerodynamic surfaces at a distance from the center of gravity incident to the pitching motion of the missile. The component of lateral velocity of such a surface in combination with the velocity due to forward speed of the missile produces an angle of attach which, in itself, provides a restoring moment.

Aerodynamic Forces, Moments, Loads

The aerodynamic effects experienced by a missile in flight. They are functions of ambient atmospheric pressure, flight Mach number, and missile size. (See Sec. 5, p. 209)

Aerodynamic Heating

The structural heating caused by energy absorption from air at stagnation temperatures at the surface of the skin.

Aerodynamic Lifting Surfaces

Missile surfaces which produce normal forces to overcome gravity or to execute a maneuver. Generally of either the double wedge, modified double wedge (having a flat section for a certain portion of the chord length) or biconvex cross-sectional profile.

Aerodynamic Report

A document covering the available detailed aerodynamic information pertinent to the design and operation of a missile. Data in this report are obtained from the results of theoretical calculations, wind tunnel and ballistic range tests, and, where possible, results of flight tests which may be available at the time the report is written and which apply to the design. The report contains the results of all analytical work carried out in obtaining the stability and control characteristics, that is, the stability derivatives and coefficients in terms of lists of these slopes and constants for various flight conditions. The overall aerodynamic operating characteristics of the design are shown. Such a report is usually broken down into divisions covering (a) the missile external aerodynamic characteristics, (b) the engine characteristics (in the case of ramjets or turbojets, but not with rockets, and (c) the overall performance characteristics.

Aerodynamic Test Vehicle

A flight test article designed specifically to obtain aerodynamic data. Most commonly used during the development phase of a missile program.

Aerodynamic Tolerances

Parametric boundaries which have adverse effects if exceeded. (See Fig. 9.2, p. 358)

Aeroelastic Effects

Structural deformations due to aerodynamic forces. (The magnitude of aeroelastic effects for any particular airframe configuration at a particular flight condition will depend on (a) the dynamic pressure q, (b) the trim conditions (which are in turn affected by cg location and Mach number, (c) structural rigidity and (d) normal acceleration. Aeroelastic effects are predominately influenced by variations in dynamic pressure and may be expected to be most serious at low altitude and high Mach number.)

Aeroelasticity

The field of study of the interaction of aerodynamic, elastic structural and inertia forces.

Aeropulse

A propulsive jet device producing thrust intermittently from intake of air as distinct from water as in the hydropulse. (See Pulse Jet).

Afterburning

(1) The characteristic of certain rocket motors to burn irregularly for some time after the main burning and thrust have ceased.

(2) The process of fuel injection and combustion in the exhaust jet of a turbojet engine (after the turbine). (Reheating, tailpipe burning, post combustion, augmentation.)

Agonic Line

(See Isogonic Line)

Aim-bias

The error between the aiming point and the center of the dispersion area of the missile trajectories. (See Fig. 10.3)

Aiming Point

The theoretical impact point at which a missile is aimed.

Air Burst

The explosion of a nuclear weapon in the air, above land or water, at a height greater than the maximum radius of the fireball.

Air Defense System

A weapon system whose mission is to defend a target complex from air attack; usually includes an early-warning radar and ground observer network; interceptors; surface-to-air guided missiles; rockets and conventional AA guns.

Airframe

The assembled principal structural elements less propulsion system, control and guidance equipments, and payload. Usually includes only the primary structure.

Air Specific Impulse

(See Specific Impulse, Air)

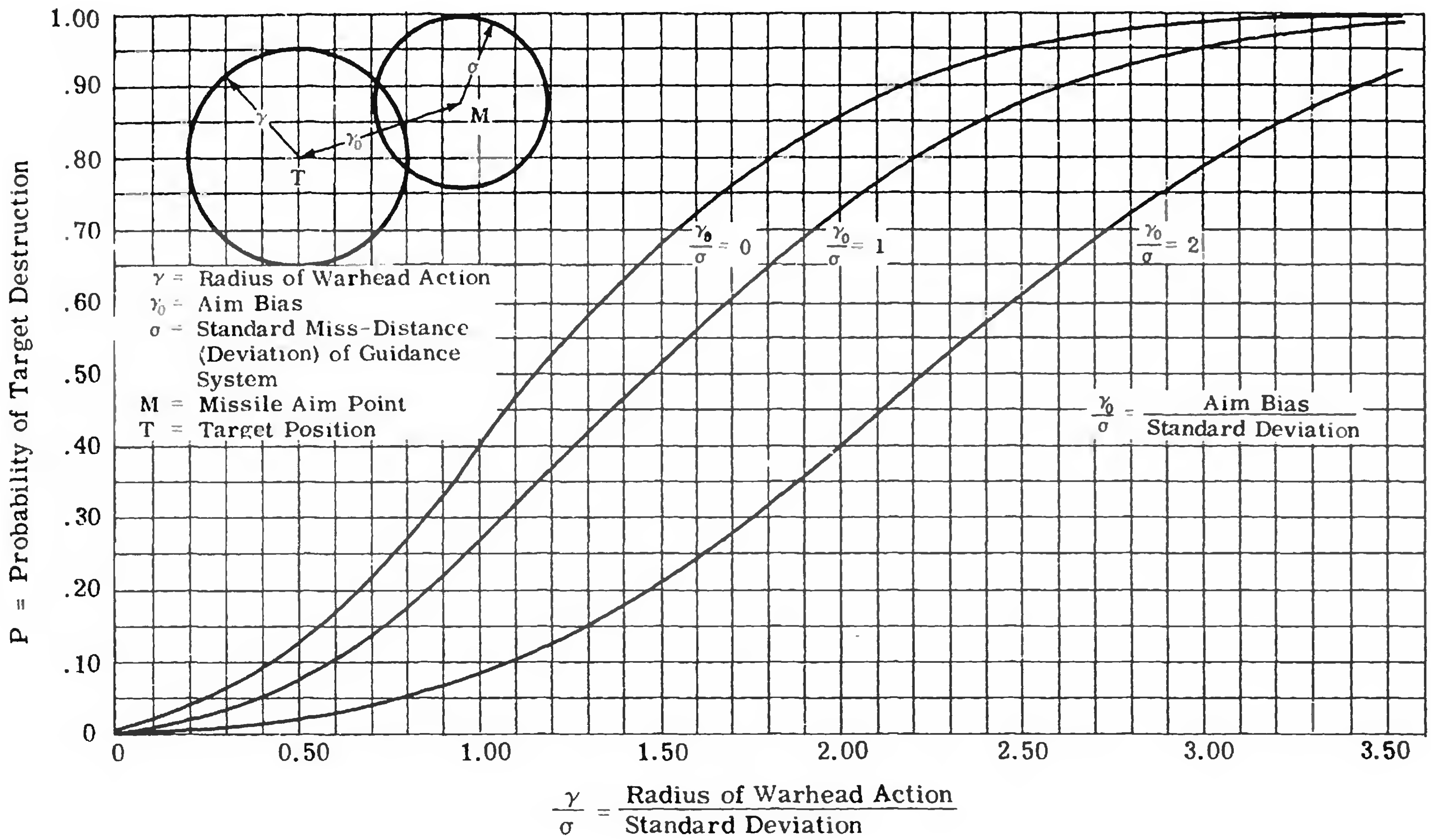
Alignment Station

A concrete structure housing the equipment to align the missile to its proper azimuth and to reference properly the gyroscope platforms.

Allowable Flutter Speed

A speed above maximum expected operation speed at which flutter may occur. (Good practice indicates that

FIG. 10.3 RELATIONSHIP OF ARMAMENT EFFECTIVENESS AND GUIDANCE ACCURACY



flutter speed should exceed maximum operation speed by at least 25 percent

Allowable Stress

If a member is so designed that the maximum stress as calculated for the expected conditions of service is less than some certain value, the member will have a proper margin of security against damage or failure. This certain value is the allowable stress, of the kind, and for the material and condition of service in question. The allowable stress is less than the damaging stress because of uncertainty as to the conditions of service, nonuniformity of material, and inaccuracy of stress analysis. The margin between the allowable stress and the damaging stress may be reduced in proportion to the certainty with which the conditions of service are known, the intrinsic reliability of the material, the accuracy with which the stress produced by the loading can be calculated, and the degree to which failure is unattended by danger or loss.

Alpha Particle

A helium nucleus consisting cf two protons and two neutrons, with a double positive charge. The alpha particle has great ionizing power but very little penetrating power and is dangerous to living tissues.

Altimeter

An instrument for indicating altitude above or below a given datum point, usually the ground or sea level. The most common form is based on the variation of atmospheric pressure with altitude; others are radio and radar.

Altitude, Absolute

Altitude with respect to the average surface of the earth as differentiated from altitude with respect to sea level. Sometimes referred to as geometric altitude.

Altitude (Max) for Rocket Propelled Missiles

The maximum altitude attainable by a vertically fired rocket. (See Eq. 8.3, p. 311)

Altocumulus Cloud

Billowed cloud of small cumuli (see cumulus) which generally form in layers. It is composed of water droplets, although it may lie either above or below the freezing level. It is a middle-level cloud. Altocumulus casts shadows and varies in color from pure white to nearly black. In general they are whitish with darker

shadows. "Mackerel sky" is an appropriate description for many altocumulus bands.

Altostratus Cloud

Translucent to opaque cloud composed of water droplets through thin layers of which the sun or moon might appear as seen on a ground-glass screen. It is a middle-level cloud in contrast to the high cirrus forms but may lie either above or below the freezing level. Very frequently, the top part of a layer of altostratus is a cirrus-type cloud, although this is not observable from below. Altostratus cast very little if any shadow but usually appear as a dull, drab, grayish sheet. Altostratus clouds following cirrus and cirrostratus is an almost certain indication that a cyclonic disturbance is approaching.

Ambient Fuze

A type of proximity fuze which is not activated as a consequence of actual determination of target presence but by the measurement of a parameter associated with the environment in which the target is normally found.

Amplidyne

A rotary magnetic or dynamo-electric amplifying device frequently used in servomechanism and control applications because of its high power gain. A single-stage device with a high degree of positive feedback.

Amplification Factor

The ratio between the response of an object flexibly supported by a structure which is subjected to a force applied over a short period of time (e.g., a shock), and the response the object would have if the same force were applied very slowly. Response may be measured in terms of force, load, displacement, acceleration, or other convenient units. Amplification is greatest when the duration of the force application corresponds to the resonant frequency of the object.

Amplifier, Autopilot

The autopilot amplifier receives signals from the outputs of gyroscope reference systems and rate gyroscopes, and converts the signals to a form usable for guidance by the actuator assemblies.

Amplifier, Buffer

(See Buffer Amplifier)

Amplifier, Linear

(See Linear Amplifier)

Amplifier, Logarithmic

(See Logarithmic Amplifier)

Amplifier, Paraphase

An electronic device sometimes used in place of transformers to operate push-pull circuits; essentially a combination amplifier and phase inverter.

Amplifier (Vacuum Tube)

(1) A device consisting of components used to increase power, voltage or current of a signal.

(2) Devices employing one or more electronic tubes to amplify an electrical signal.

Class A - The grid potential always remains between two potentials and the grid flow never goes positive. (Characteristics: good linearity, good power and voltage amplification; poor efficiency)

Class B (Push-Pull) - Two tubes used in parallel with a negative grid bias. (Characteristics: good linearity and power efficiency)

Class A-B - The grid bias and alternating grid voltages are such that the plate current in a specific tube flows for appreciably more than half but less than the entire electrical cycle.

Amplifier, Video

(See Video Amplifier)

Amplitude

A measure of the magnitude of maximum deviation from a "rest condition". Amplitude may be expressed either in a positive or a negative direction for force, displacement, velocity, or acceleration. For sinusoidal motion the amplitudes are one-half the peak-to-peak values. In electronics, it is a measure of the maximum signal, positive or negative, from the average of the quiescent value.

Amplitude, Acceleration

Amplitude expressed in terms of the acceleration inherent in the change of direction of motion of a particle vibrating at a given amplitude and frequency. For a sinusoidal motion, this relation is shown

by the expression:

$$a = A\,(2\pi)^2 f^2$$

where a is the acceleration in distance-time units,
A is the amplitude in linear units and,
f is the frequency in cycles per second.

Dividing both sides of the equation by the acceleration of gravity, the acceleration in g's is approximated by:

$$G = 0.1\frac{A}{2}f^2$$

if the amplitude is measured in inches. (See Fig. 4.57, p. 188)

Amplitude Distortion

(See Distortion, Harmonic)

Amplitude, Double

(See Amplitude, Peak-to-Peak)

Amplitude Modulation

(See Modulation, Amplitude)

Amplitude, Peak-to-Peak

The algebraic difference of the positive and negative magnitudes of maximum deviation from the rest condition; also termed double amplitude.

Anabatic Wind

A wind blowing uphill. In general, anabatic winds refer to winds originating in connection with surface heating, such as a breeze blowing up a valley when the sun warms the ground.

Analog

The representation of one system in terms of the characteristics of another, e.g., electrical circuits can be used to represent mechanical or acoustical systems. (See Fig. 10.4)

Analog Computer

An electronic calculating machine in which quantities and relationship are represented by continuously variable physical quantities such that approximate solutions can be obtained readily. (At present, the analog computing system is the principal device used for simulation of dynamic problems in the study of the control loop and system performance associated with a missile's ability to respond to received signals.) In an analog computer quantities are represented without explicit use of language.

FIG. 10.4 MECHANICAL FUNCTIONS AND ELECTRICAL ANALOGS

Mechanics	Electric Analog
Where s = distance m = mass t = time k = elastic constant p = period of vibration	Where Q = quantity L = inductance t = time C = capacitance p = period of oscillation
Mean velocity, $V = \frac{s}{t}$	Current, $I = \frac{Q}{t}$
Instantaneous velocity, $v = \frac{ds}{dt}$	$i = \frac{dq}{dt}$
Acceleration, $a = \frac{v - v_0}{t} = \frac{dv}{dt}$ when $V_0 = O$ $v = at$ $s = 1/2\ at^2$	
Momentum = mv Force, $F = \frac{mv - mv_0}{t} = ma = m\frac{dv}{dt}$	Electromotive force, $E = \frac{LI - LI_0}{t}$
Weight (force of gravity) = mg	$e = L\frac{di}{dt}$
Centrifugal force $= \frac{mv^2}{r}$ where r = radius of path	
Work (Energy), $W = Fs = mas = 1/2\ mv^2$	$W = EQ = EIt = 1/2\ LI^2$
Power, $P = \frac{W}{t} = FV$	$P = EI$
Displacement of spring, s = Fk Period of vibration, $p = 2\pi\sqrt{km}$	Capacitor charge, Q = EC Period of oscillation, $p = 2\pi\sqrt{CL}$

Ancillary Equipment

An equipment of a guided missile not directly employed in its operation, but necessary for logistic support, preparation for flight or assessment of target damage: e.g., test equipment, vehicle transport.

Anelasticity (Internal Friction)

In general, any deviation from the ideal behavior postulated by classical elasticity theory (where the strain is proportional to the applied stress and follows instantaneously upon its application). The term is applied particularly to those phenomena associated with the damping of elastic waves in solids. Numerous causes are known for these effects, such as thermal diffusion, motion of grain boundaries, diffusion of twin boundaries, atomic solution diffusion, etc. The damping associated with a given process depends strongly on the frequency of the elastic wave.

Angle-of-Attack, Induced
The difference between the actual angle-of-attack and the angle-of-attack for infinite aspect ratio of an airfoil for the same lift coefficient.

Angstrom Unit (Å)
A unit of length equal to one ten-thousandth of a micron, or one hundred-millionth of a centimeter. Used to express the length of extremely short waves.

Anisoelastic
(See Nonisoelastic Effects)

Anode
The radio tube electrode to which the main electron stream flows. It is commonly called the plate, and is usually placed at high positive potential with respect to the cathode. It is usually identified on diagrams by the letter P.

Anodized Coating
A process used for coating aluminum and aluminum alloys. Used for corrosion resistance provided by the aluminum hydroxide surface. The surface is soft and must be treated with a coat of primer before handling. Anodizing is not a plating process. The coating is applied by a chromic acid oxidation process.

Antenna Array
Designates two or more antennas coupled together.

Antenna, Bandwidth of
The range of frequencies within which the performance of an antenna, in respect to some characteristic, conforms to a specified standard.

Antenna, Cosecant-Squared
An antenna designed to produce special polarization effects wherein the power density pattern varies as the square of cosecant of an angle defined by a line parallel to the earth's surface and the slant range line of sight. (Used in airborne antennas to lay down a uniform electric field intensity along a line on the earth's surface.)

Antenna Cross Talk
A measure of undesired power transfer through space from one antenna to another. Numerically, antenna cross talk is the ratio of the power received by one antenna to the power transmitted by the other, usually expressed in decibels.

Antenna, Dipole
A center-fed antenna, which is constructed to be approximately one-half as long as the wave length it is designed to transmit or receive; essentially a resonant transmission line system. Also termed Half Wave Antenna.

Antenna, Dish
A continuous or perforated concave antenna usually contoured to a parabolic shape used for transmitting and/or receiving radio frequency waves.

Antenna Gain
A measure of the directivity of the antenna field pattern as compared to a standard dipole antenna; the ratio of the power that must be supplied to the standard antenna to deliver a certain field strength in the desired direction to the power that must be supplied to the directional antenna to obtain the same strength in the same direction. (See Fig. 6.15)

Antenna, Horn
The flared end of a radar wave guide, designed for efficient radiation of energy from within the guide to space over a comparatively wide frequency range.

Antenna Multiplex Coupler
Combines the FM outputs of several telemetering packages into one composite FM signal. The signal is applied to the telemetering antennas for transmission to the ground equipment.

Antenna, Notch
An antenna in which the pattern is formed by a notch or slot in a radiating surface. Characteristics are similar to a properly proportioned metal antenna and may be evaluated with similar techniques.

Antenna, Omnidirectional (or Beacon)
An antenna having essentially uniform response in all directions.

Antenna, Pattern
A diagrammatic representation of the radiation field from an antenna, usually in terms of loci representing equal power levels. The radiation characteristics vary inversely as the square of the distance and depend on direction from the source. (See Fig. 6.7, p. 241)

Anticlastic Curvature
Curvature of an edge loaded thin sheet under compression due to the Poisson effect.

Antinode
In a vibrating system, a surface composed of particles which have larger amplitudes than nearby particles.

Apogee
The highest point of a trajectory; more precisely for an elliptical orbit, the point of intersection of the trajectory and its semi-major axis. The term is borrowed from celestial mechanics, where it refers to that point in the orbit of any celestial body which is at the greatest distance from the center of the earth; apogee is the opposite of perigee. Note that the apogee is a point, not a distance.

Approach Apron
A concrete apron adjoining the erection area that provides a solid support surface for transtainers and other ground handling equipment.

Arithmetic Unit
That part of a computer which performs arithmetic operations.

Arming
(1) The act of completing the firing signal transfer path through the S and A (Safety and Arming System).
(2) The process of changing a fuze or a warhead from a safe condition to a state of readiness for initiation.

Arming Altitude
The altitude dictated by the combined effects of several extreme conditions: the maximum desired burst height, the highest target elevation expected.

Armament System
A triad of missile components; fuze; safety and arming mechanism and warhead – which are used to produce and control the damage effects of a missile.

Armed
That condition of the safety and arming mechanism which permits warhead detonation by fuze action.

Arming System
(See Safety and Arming Mechanism.)

Artillery Mil
(See Mil)

Ascent Path
Flight path leading from the surface of a celestial body into an orbit in space.

Askania Phototheodolite
A type of cine-theodolite manufactured by the Askania Regulator Company. (See Theodolite)

Aspect Ratio
(1) The ratio of the square of the span to the total area of an airfoil. In wingless missiles, the ratio of body diameter to its mean length.

$$AR = b^2/S_w$$

(2) In television the numerical ratio of frame width to frame height nominally standardized as four units horizontally to three units vertically.

Assembly (or Subassembly)
A commonly mounted group of component parts which may be subject to disassembly and which is not capable of performing a complete operation by itself: e.g. (assemblies when an integral part of a component, i.f. strip, a terminal board with component parts attached).

Asteroid (Astron)
A starlike body, especially one of the numerous small planets, nearly all of whose orbits lie between Mars and Jupiter. Also termed Planetoid and Minor Planet. (See Planetoid)

Astrionics
The science of electronics as employed in astronautics.

Astronautics
The science dealing with space and space travel. (See Cosmonautics)

Astrophysics
The physics of astronomical bodies, including the study of stellar light, energy sources, constitution of celestial bodies, etc.

Athodyd (Aero THermODYnamic Duct
A ramjet.

Atmosphere
The gaseous envelope which surrounds the earth. Arbitrarily subdivided with increasing altitude into the troposphere (0 to 10 miles); the stratosphere (10 to 20 miles); the chemosphere (20 to 50 miles); the ionosphere (50 to 250 miles;

and the mesosphere (from about 250 to space). (See Fig. 10.5)

Atmosphere, ICAO

A standard atmosphere promulgated by the International Civil Aeronautics Organization. This standard atmosphere includes characteristics (e.g., properties, composition, etc.) from sea level to 100,000 ft (the Minzner extension from 65 to 100,000 ft). (See Fig. 2.4, p. 29)

Atmospheric Attenuation

Reduction in the intensity of the manifestations of a nuclear detonation (nuclear thermal radiation and air blast) caused by the earth's atmosphere. (See Fig. 6.18, p. 252)

Atmosphere, Model

A hypothetical atmosphere based on the temperature function by layer. Each layer has a temperature gradient linear with geopotential altitude but whose first derivatives are discontinuous at the intersection of the layers.

Atmosphere, Standard

(See Standard Atmosphere)

Atmospheric Pressure

The pressure upon a body in the atmosphere due to the weight of air above it. (See Fig. 2.4, p. 29)

Atom

The smallest part of an element which can participate in ordinary chemical changes. The atoms of a given element are unvarying in average mass, but are different in such mass from atoms of all other elements.

Chemically, the smallest electrically neutral constituent part of an element that can take part in a chemical reaction.

Physically, a positively charged nucleus surrounded by a compensating number of negative electrons in various orbits.

Atomic Clock

A very accurate source of frequency (or time) which depends upon the invariant nuclear resonance of certain elements such as caesium when subjected to a RF electromagnetic field. Accuracies of one part in 10 m. are achievable.

Atomic Device

Any device that makes use of nuclear fissionable, radioactive material, especially an atomic bomb, shell, or other atomic missile.

Atomic Number

The number of excess positive charges on an atomic nucleus. The essential feature which distinguishes one element from another and which determines the position of the element in the periodic table. (See Fig. 1.5, p. 19)

Atomic Power

The power (energy) released by a nuclear reaction.

Atomic Weight

The weighted mean of the masses of the neutral atoms of an element expressed in atomic weight units. Unless otherwise specified it refers to a naturally occurring form of the element. The Atomic Weight unit, awu, is exactly one-sixteenth of the weighted mean of the masses of the neutral atoms of oxygen of isotopic composition found in fresh lake or rain water: 1 awu = 1.660×10^{-24} gm = 1.000272 amu. The experimentally determined ratio of the atomic weight unit to the atomic mass unit is called the atomic mass conversion factor. The value of this factor is uncertain in the seventh significant figure because of variations in the isotopic composition of oxygen from different natural sources. In the future its value, and hence that of the atomic weight unit, may be rendered exact by definition.

Attenuation

The loss of effectiveness of an emission because of the distance it travels. (See Eq. 6.19, p. 252, and Fig. 6.18, p. 251)

Attenuator

(1) A device designed to cause a loss in energy in a transmission system without introducing appreciable distortion in the desired frequencies.
(2) A resistive network for reducing amplitude of an electrical signal without appreciable phase or frequency distortion.

Attitude

The position of a missile as determined by the inclination of its axes to some frame of reference. If not otherwise specified, this frame of reference is fixed to the earth.

FIG. 10.5 CHARACTERISTICS OF THE EARTH'S ATMOSPHERE

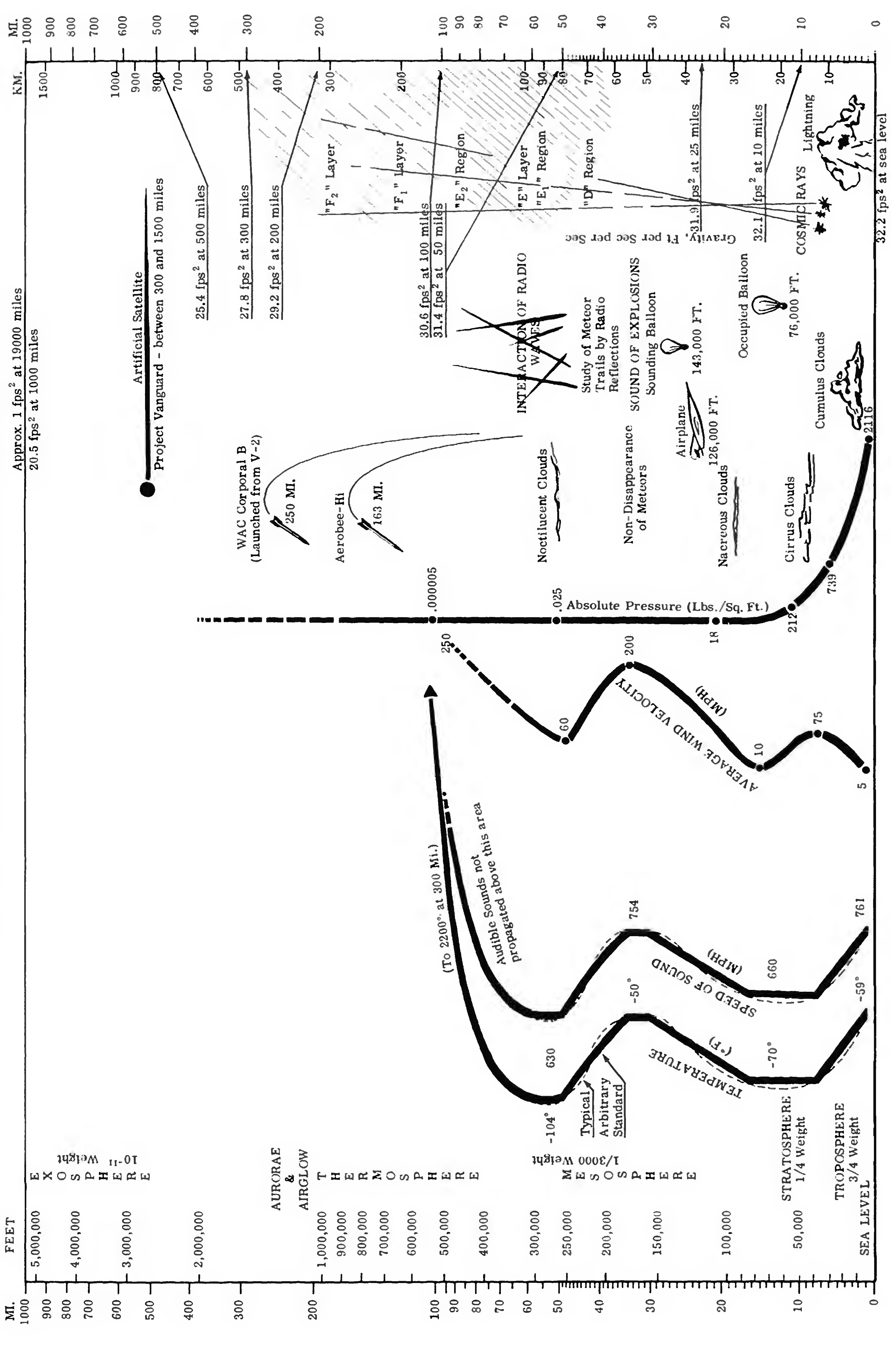
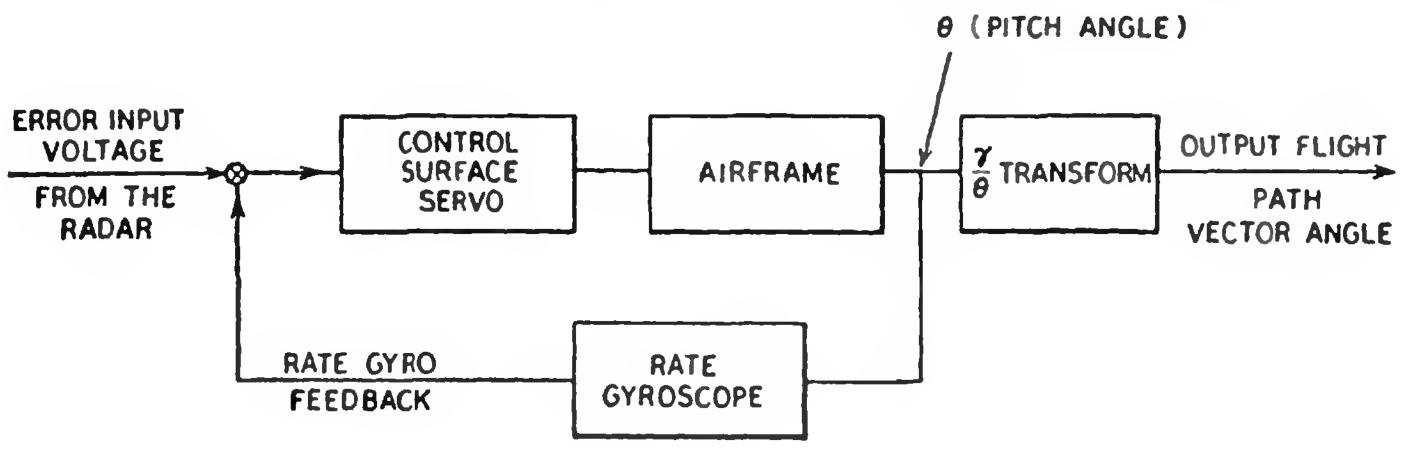


FIG. 10.7 AUTOPILOT LOOP BLOCK DIAGRAM



Attitude Control
A system which aligns a missile or vehicle portion of a missile to a desired flight path.

Attitude Control System
(See Automatic Pilot)

Attributes, Method of
Measurement of quality by the method of attributes consists in noting the presence or absence of some characteristic (attribute) in each of the units in the group under consideration and counting how many do or do not possess it. e.g., Go and Not-Go gaging of a dimension.

Attrition
Destructive military action which denies the enemy the use of his resources and materials; a gradual reduction in numbers, usually owing to enemy action.

Audio
Pertaining to frequencies of audible sound waves between about 20 and 20,000 cycles per second.

Augmented Thrust Ratio
The ratio of thrust obtained by a turbojet with its afterburner operating to that without. (See Eq. 7.3.7, p. 285)

Augmentor
In a jet engine, a duct usually enclosing the exhaust jet behind the nozzle exit section to provide increased thrust. (See Afterburning)

Automatic Celestial Navigation
(See Star Tracking; Navigation, Celestial)

Automatic Control System
(See Control System, Automatic)

Automatic Frequency Control (AFC)
A circuit which generates a low frequency correction to maintain the intermediate frequency at its correct value, (performed by frequency modulating the local oscillator at an audio rate to provide a carrier).

Automatic Gain Control (AGC)
A means of accomplishing regulation of the magnitude of the output signal level of a system.

Automatic Pilot
An automatic control device for keeping a missile in level flight and on a set course or for executing desired maneuvers. Sometimes termed gyropilot, mechanical pilot, robot pilot, autopilot. (See Fig. 10.7)

Automation
The technique of improving human productivity in the processing of materials, energy and information by utilizing in various degrees, elements of self-control and of automatically executed product programming.

Autopilot Amplifier
(See Amplifier, Autopilot)

Autosyn (AUTOmatically SYNchronous)
A Bendix Aviation Corporation trade name for a synchro. (See Synchro)

Autotrack
(See Radar, Lockon)

Average Error
(See Mean Absolute Error)

Average Load
(1) A qualitative term used in the design of shipping containers to denote an item (or items) of low or moderate density, which, when packed directly into a shipping container, provides non-shifting support at several points on each face of the container.
(2) More often, the arithmetical average of a load over a complete loading cycle.

Avionics (AVIation electrONICS)
A coined term describing the field of airborne electronics and associated control systems.

Axial Compressor

A compressor employing many stages, each consisting of a rotor and a stator member. The rotor adds kinetic energy to the air stream in an axial direction, and the stator converts this kinetic energy into pressure energy. The outlet velocity of the air is usually equal to that at the inlet.

Azimuth

A direction expressed as a horizontal angle usually in degrees or mils and measured clockwise from north. Azimuth may be true azimuth, or magnetic azimuth depending upon which north is used.

Azimuthal Equidistant Chart

A modification of the polar gnomomic chart in which the parallels of latitude increase uniformly in radius so that the latitude scale is constant.

AZUSA

A guidance or range instrumentation system using directive antennas and phase comparison (coherent carrier) techniques for angle determination and multichannel subcarriers for range (distance) measurements by means of time delay. Equipment includes an elaborate ground antenna array, a transmitting and receiving station and a missile borne transponder. The system was developed by Convair.

B

BFO

(See Oscillator, Beat-frequency)

BI-APS

(See Battery Inverter Accessory Power Supply)

BI-Propellant

Oxidizer (lox) and fuel (RP-1) combined (or any other combination).

BOD

(See Beneficial Occupancy Date)

BSE

(See Base Support Equipment)

Backfit

(See Retrofit)

Backlash

In servo applications, the dead space or unwanted movement in a control system incident to imperfect fabrication.

Back-scattering

The radiation of unwanted energy to the rear of a radar antenna.

Backscratcher

A coined word to describe an umbilical connection to a missile - usually of the flush type.

Backward Wave Oscillator

(See Oscillator, Backward Wave)

Ballistic Camera

A camera used to photograph high velocity phenomena. Usually fixed in position with continuously open shutters or with very high frame speed so that successive images at precise times are available for study.

Ballistic Guided Missile

(See Missile, Guided Ballistic)

Ballistic Missile

(See Missile, Ballistic)

Ballistic Pendulum

An instrument used for measuring the velocity of a projectile. In its usual form it consists of a simple pendulum of mass M, and of natural fruquency f. A projectile of mass m, moving with a velocity V strikes the bob perpendicularly and is imbedded in it. The maximum excursion X of the bob is then measured. Assuming that $M \gg m$ and that little damping is present, it may be shown by application of conservation laws that

$$V = \frac{2\pi fXM}{m}$$

Ballistics, Exterior

That branch of the science of ballistics which deals with the laws and principles governing the motions of projectiles and missiles in flight.

Ballistics, Interior

That branch of the science of ballistics which deals with the laws and principles governing the motions of projectiles and missiles in a gun barrel or its functional equivalent.

Ballistite

A colloidal propellant composed of nitroglycerin and nitrocellulose formed with the aid of a solvent. Invented by Alfred Nobel in 1888.

Balloon Tanks

Propellant or fuel tanks which depend on internal pressure to stabilize the tank walls for compressive load carrying capability.

Band-Elimination Filter
Two or more tuned circuits adjusted to attenuate highly a band of frequencies within predetermined upper and lower frequency limits. The graphical result (selectivity curve) is ideally an approximation to a square wave which has the required width.

Band-Pass Filter
(See Filter, Band-Pass)

Bandwidth
The difference in frequencies between the lowest and highest effective frequencies; may refer to a tuned circuit, modulated radio signal, servomechanism, or radio station channel assignment, etc.

Bang-Bang Control
(See Control, Bang-Bang)

Baroport
An opening on an aerodynamic surface where the effects of velocity on local air pressure introduce the least uncertainty in predicted altitude versus pressure relationships.

Baroswitch
A pressure-sensitive device which provides a signal to a circuit.

Barn
A unit of area equal to 10^{-24} cm^2. Cross sections per atom are customarily measured in barns.

Base
(See Base Complex; Launch Base Area)

Base Complex
An air base for support of Air Force units consisting of launching pads and all components or related facilities for which the Air Force has operating responsibility, together with interior lines of communication and the minimum surrounding area required for local security. (See Launch Base Area)

Base Hardness
A description of the degree to which a missile facility installation is protected against enemy inflicted damage. (See Soft Structure, Hard Structure)

Base Pressure
The pressure at the rear or base of a missile. The base pressure has a large negative value with reference to the free stream pressure, thereby creating considerable drag, especially if the base is large. (The presence of a jet at the rear of a missile will decrease the effective base area as long as the jet is in operation.)

Base Support Equipment (BSE)
That portion of the unit mission equipment for tactical operation units which permits the establishment of base-type functions necessary to support a tactical mission.

Base Surge
A concentrated wave or cloud of mist or dust which shoots out from the foundation of the column by an underwater or underground nuclear explosion.

Basic Frequency
(See Frequency, Basic)

Basic Load
(See Load, Basic)

Battery Inverter Accessory Power Supply (BI-APS)
The BI-APS is a battery-motor-alternator combination that supplies electrical power for missile operation.

Battery, Primary
A self-contained source of electrical energy which is characterized by the need to renew the chemically reacting parts (e.g., dry cell).

Battery, Reserve
A self-contained source of electrical energy which is characterized by long shelf life in an unenergized state. Electrolyte is added when battery power is desired.

Battery, Secondary
A self-contained source of electrical energy which is characterized by reversible electro-chemical processes. The chemically reacting parts are restored, after partial or complete discharge, by reversing the direction of current flow through the battery. (e.g., wet cell)

Battery, Thermal
A series of electrochemical cells that are activated by applying heat to melt a solidified electrolyte.

Battleship Design
A heavy structure simulating an airborne article and having certain, usually very rugged characteristics to permit special tests.

Beacon
A device which serves as a signal emitter for use as a guidance or warning aid. Radar beacons aid the radar set in locating and identifying special targets which may be difficult or impossible to sense otherwise.

Beacon, Radar
Generally an omnidirectional radiating device, containing an automatic radar receiver and transmitter (transponder), that receives pulses (interrogations) from a radar and returns similar pulses or sets of pulses (responses). The beacon response may be on the same frequency as the radar, or may be on a different frequency. (See Fig. 10.8)

Beam Jitter
In a beam-rider guidance system, a small oscillatory, angular movement induced into the radar antenna array, and consequently into the radar beam. This movement is caused by:
(a) the necessity of having to develop an error signal, when in automatic tracking, before the antenna will change its position, or
(b) the circuitry intentionally being made "tight" to obtain plus and minus tracking errors rather than only lagging errors, or
(c) gear play in the radar tracking head.

Beam Rider
(See Beam-Riding System)

Beam-Riding System (Beam Rider)
A guidance system in which the missile is directed along a line (often the line-of-sight) between the beam source and the target no matter whether corrective control commands are generated automatically within the missile (true beam-rider) or at a control point on the ground and transmitted to the missile (command system). (See Guidance, Beam Rider) (See also Fig. 10.9 and 10.10)

Beam Width
The angular separation in azimuth between the two directions to the right and left of the center of the beam, at which the gain is one-half that at the center. Beamwidth may be measured also in elevation, in the vertical plane, or in an enclosed plane. (See Side Lobe; Half Power) (See also Fig. 6.16, p. 249)

Beast (Bird)
A slang term for a missile.

Beat Frequency
(See Frequency, Beat)

Beat-Frequency Oscillator (BFO)
(See Oscillator, Beat-frequency)

FIG. 10.8 RADAR BEACON SYSTEM

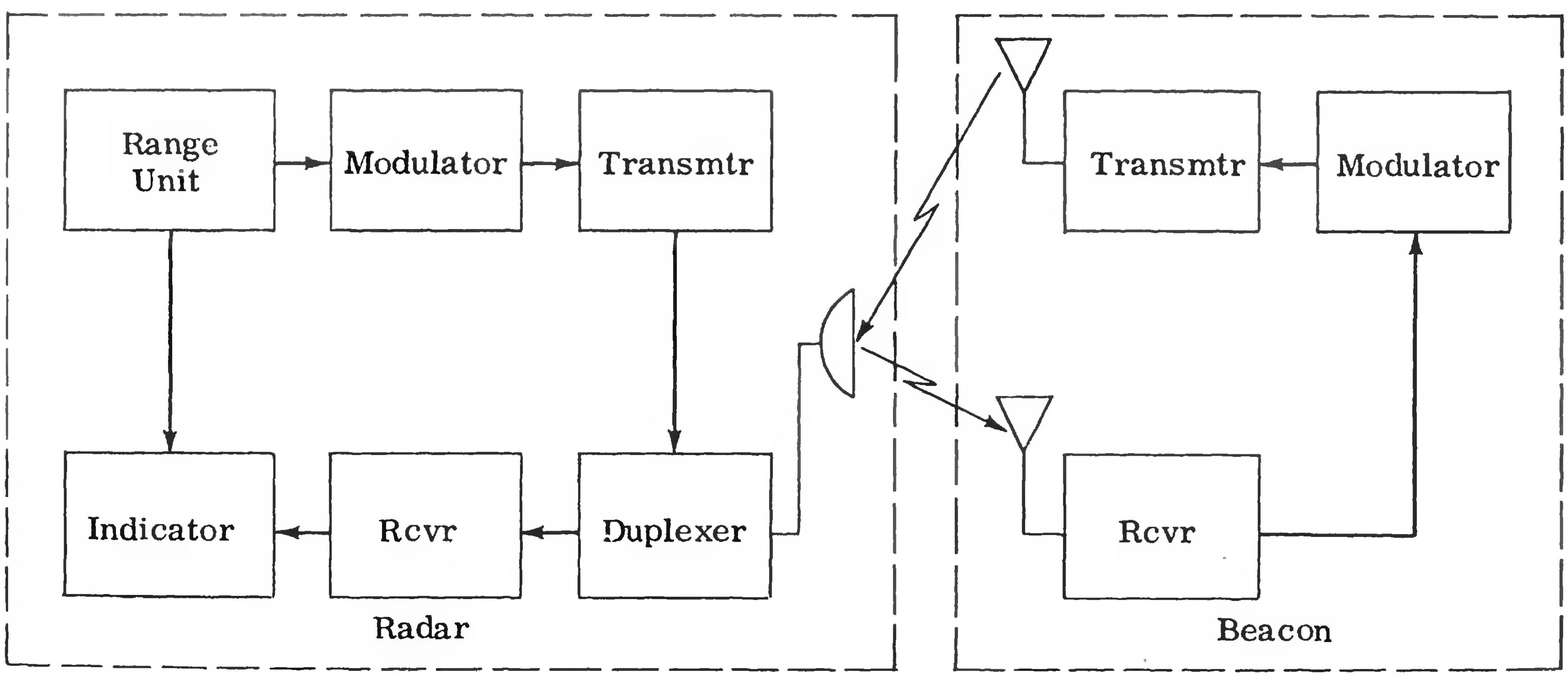
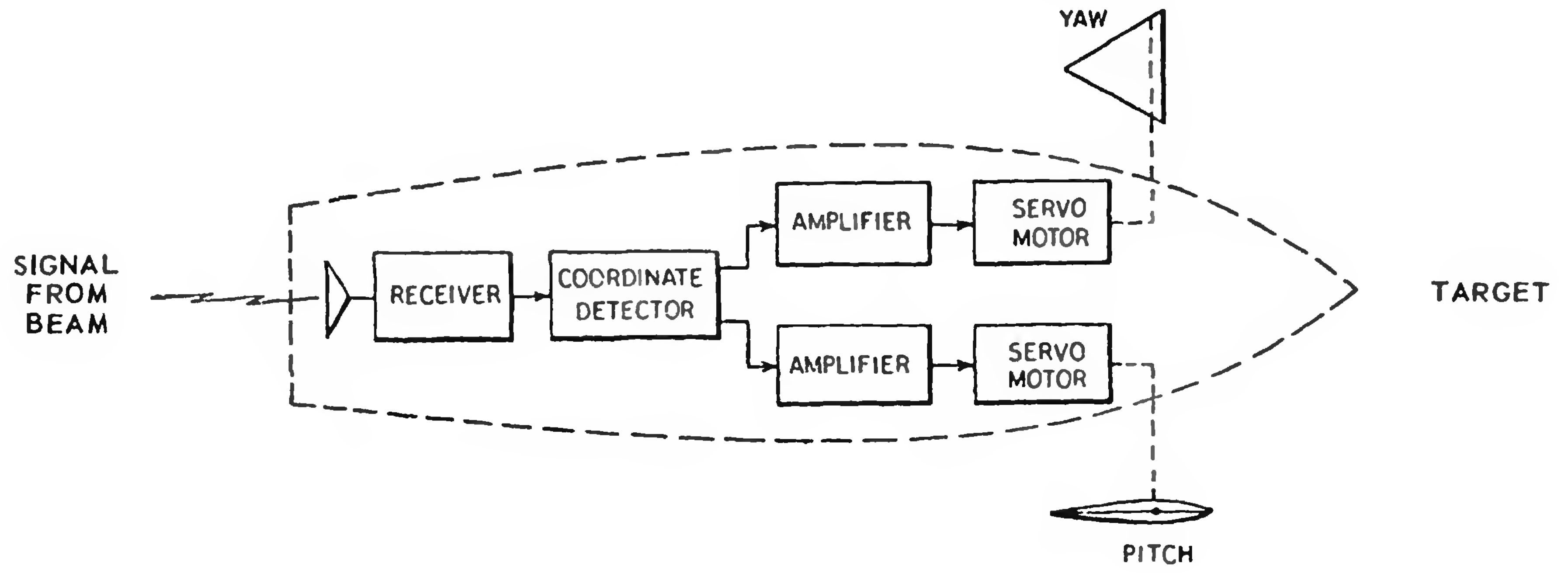


FIG. 10.9 BEAM RIDER GUIDED MISSILE



Beaufort Wind Scale

An arbitrary scale of wind velocities.

Code Number	Wind Velocity (m.p.h.)	Description
0	0-1	Calm
1	1-3	Light air
2	4-7	Light breeze
3	8-12	Gentle breeze
4	13-18	Moderate breeze
5	19-24	Fresh breeze
6	25-31	Strong breeze
7	32-38	Moderate gale
8	39-46	Fresh gale
9	47-54	Strong gale
10	55-63	Whole gale
11	64-75	Storm
12	Over 75	Hurricane

Beeper

A slang term for an individual who directs a pilotless aircraft or missile by remote control.

Belgium Block Course

An environmental test facility for evaluating the transportation environment. The course is a specially prepared road bed having varying degrees of roughness, waviness, and other controlled characteristics over which wheeled equipment is moved at varying speeds to study the effect of transportation shock and vibration.

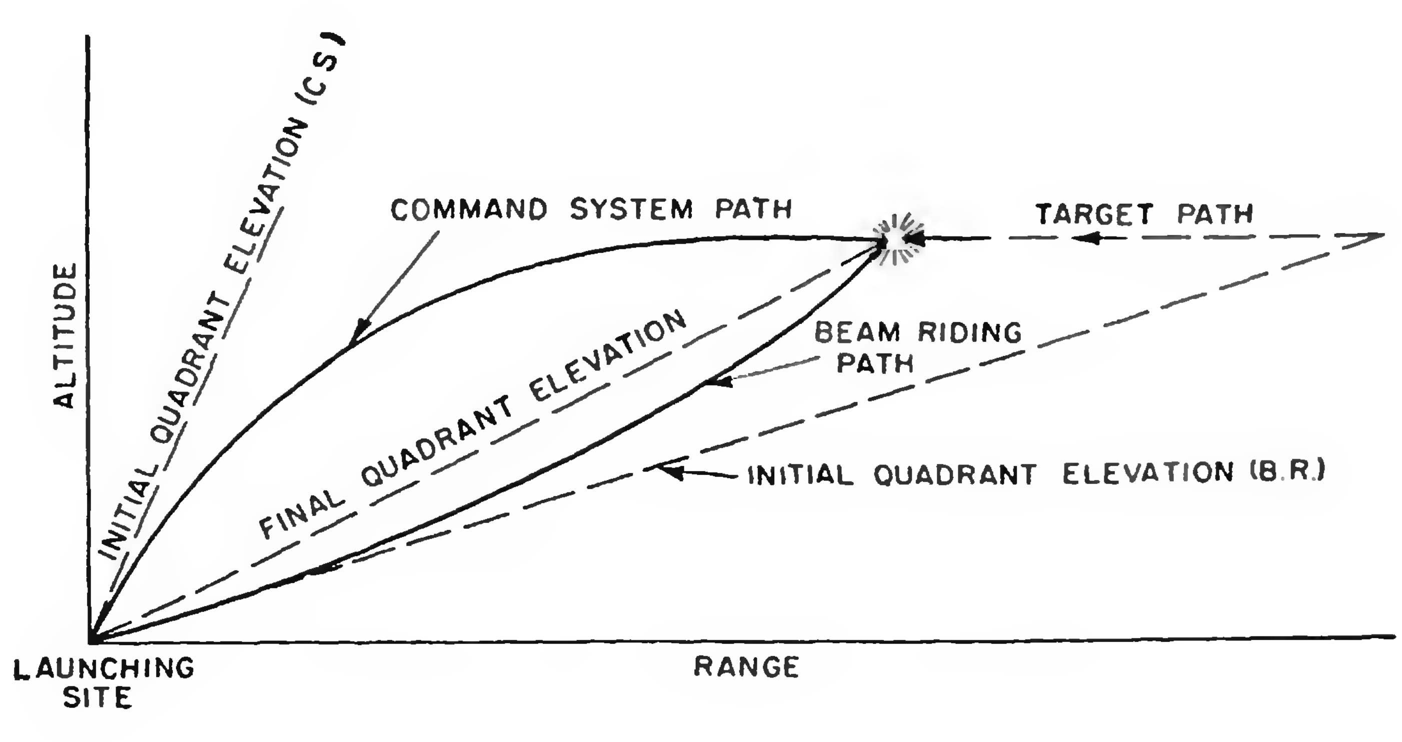
Beneficial Occupancy Date (BOD)

That date when buildings and/or other construction will be completed to a point which will permit occupancy by a unit or organization and installation team for the purpose of installing unit equipment and special and/or fixed equipment that is not included as installed equipment. Operational use is possible as soon as unit and special equipment are in place.

Bernoulli's Theorem

If the chance of an event occurring upon a single trial is p, and if a number of independent trials is made, the probability that the ratio of the number of successes to the number of trials differs from p by less than any preassigned quantity however small, can be made as near certain as may be desired by

FIG. 10.10 COMMAND & BEAM RIDER FLIGHT PATHS



making the number of trials sufficiently large. The theorem may be restated: "If the probability of an event is p, and if an infinity of trials is undertaken, the proportion of successes is sure to be p."

Beta Particles

Charged particles emitted from a nucleus and having a mass and charge equal in magnitude to those of the electron. Sometimes termed a high speed electron. Dangerous to living tissues.

Bickford Fuse

A central core of black powder surrounded by a protective shield. Also known as miner's or safety fuse. Used for communicating fire. Burns at a rate of about 1 ft/min.

Binary Code

A process or means of identifying the digits in a binary system, e.g., pulses varying in duration or spacing.

Binary Number System

A number system which uses two symbols (usually denoted by "0" and "1") and has two as its radix, just as the decimal system uses ten symbols ("0, 1, ... 9") and has ten as its radix. (See Radix)

Binomial Distribution

If the probability of an event occurring in a single trial is p, the chance that it occurs exactly n times in m independent trials is

$$P_m(n) = \frac{m!}{n!\ (m-n)\ !}\ p^n\ (1 - p)^{m-n}$$

where

$P_m(n)$ = probability that the event occurs n times in m independent trials

p = probability of the event occurring in a single trial

Bird (Beast)

A slang term for a missile.

Bit (Binary DigIT)

A choice between two equiprobable events; the number of elements or marks used to represent each discrete quantity or value in a set of measurements, thereby determining the accuracy of representation, e.g., 10 bits would allow a quantity to be measured or represented to an accuracy of one part in $2^{10} = 1024$.

Black Body

An object that absorbs all of the radiation falling on it, neither reflecting nor transmitting any of the radiation.

Black Box

(1)A term used loosely to refer to any sub-component that is equipped with "connects" and "disconnects" so that it can be readily inserted or removed from a specified place in a larger system (e.g., the complete missile, or some major subdivision) without benefit of knowledge of its detailed internal structure.

(2)A term pertaining either to the functional transformation that acts upon a specified input to give a particular output, or to the apparatus for accomplishing this transformation (without regard to the detailed circuitry used).

Blast

The brief and rapid increase in air pressure resulting from the detonation of any explosive matter.

Blast Cluster Warhead

(See Warhead, Blast Cluster)

Blast Warhead

(See Warhead, Blast)

Blip

(See Pip)

Block Diagram

A line drawing used to describe the functional interrelationship among components of a system.

Blockhouse

A building, usually heavily reinforced and near the launch site, that houses the electronic equipment and controls for preparation and firing of the missile, together with auxiliary apparatus.

Blocking Capacitor (or Condenser)

Any capacitor used in a radio circuit to block the flow of direct current while allowing AC signals to pass.

Blocking Oscillator

(See Oscillator, Blocking)

Blow-Out Disc

A mechanism consisting generally of a thin metal diaphragm, used in a solid rocket as a safety measure against excess gas pressure in the combustion chamber.

Blue Phone Line
A party line telephone system which provides a link between personnel involved in countdown procedure. All conversations are tape recorded.

Boattail
The cylindrical section of a missile body where the diameter is continually decreasing toward the rear. The principal purpose of a boattail is to reduce the over-all aerodynamic drag of a missile airframe.

Bode Chart (or Diagram)
A plot of phase versus frequency or gain versus frequency to describe the frequency response characteristics of an amplifier, servo or other device. (See Fig. 9.17, p. 383)

Body Hardware
Fittings and parts connected to the airframe assembly.

Body Lift
Aerodynamic lift on a fuselage or missile body resulting from an angle of attack of the body.

Body Mounted Gyroscope
A gyroscope mounted directly on the airframe, thus using it as a reference instead of a stabilized platform.

Bogey Weight
(See Weight, Bogey)

Boil-off
The vapor loss from any volatile liquid, e.g., liquid oxygen; particularly when stored in a missile ready for flight.

Bolometer
(1) A very sensitive type of metallic resistance thermometer, used for measurements of thermal radiation. (See Detector, Infrared)
(2) In electronics, a small resistive element capable of dissipating microwave power, and using the heat so developed to effect a change in its resistance, thus serving as an indicator; commonly used as a detector in a low, and medium, level power measurement.

Bonded Grain, Case
(See Grain, Case Bonded)

Booster
(1) In warheads, a high-explosive element sufficiently sensitive to be actuated by small explosive elements in a fuze and powerful enough to cause detonation of the main explosive filling.
(2) In the launching system, an auxiliary propulsion system which travels with the missile and which may or may not separate from the missile when its impulse has been delivered. A booster system may contain or consist of one or more units. (See Jato)

Booster Assembly
The structure which is used with some missile types to support one or more Jatos, transmit the thrust to the missile, and orient the thrust line with respect to the center of gravity of the combination.

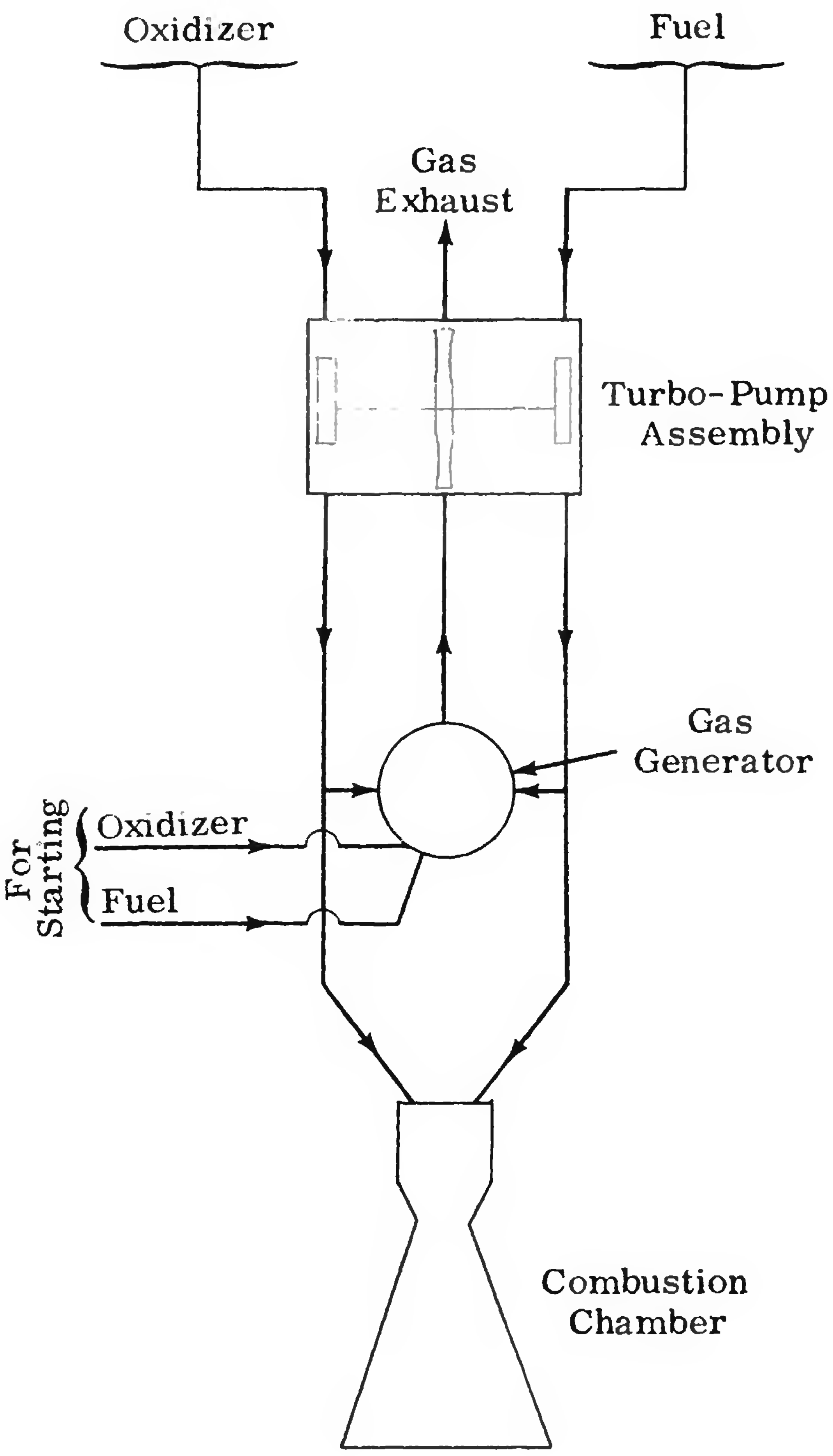
Booster Rocket
An application of a rocket to a missile for a purpose of providing initial velocity. Boosters are used to attain speeds required for initiation of ramjet engine operation, provide rapid accelerations, assist in takeoff, etc. The initial stage of any two (or more) stage missiles is termed the booster.

Booster Impact Area
The area, downrange and along the line of flight, where booster rockets strike the surface of the earth after having been detached from a missile at staging or end of boost phase.

"Boot-strap" Operation
In liquid rocket engine usage, a regenerative process used for starting. A portion of the turbopump output is fed back to the gas generator which causes an increase in available energy for driving the turbopump, which in turn delivers a greater quantity of propellants to the gas generator. The cycle terminates when rated system performance has been attained. (See Fig. 10.11)

Bore Sighting
The process by which the axis of a gun bore and the line-of-sight of a gun sight are made parallel or are made to converge on a point. Also the alignment of a radar beam with a fixed target to obtain initial settings.

FIG. 10.11 "BOOTSTRAP" OPERATION



Boresight Tower

A tower on which there are mounted a visual target and an electrical target (an antenna fed from a signal generator); these targets are used for the parallel alignment of the electrical axis of a receiving antenna and the optical axis of a telescope mounted on the antenna.

Boundary Layer

The thin region of nearly static fluid near the surface over which the fluid stream is moving. (See Figs. 5.3 and 5.4, p. 219)

Bowen-Knapp Camera

A very high speed, strip film ballistic camera used for missile flight test documentation.

Breeding

The process whereby a fissionable species is utilized as a source of neutrons to produce more nuclei of its own kind than are used up. This is the function of a breeder reactor.

Brennschluss (Burnout)

The end of combustion in a rocket.

Brisance

The shattering effect of an explosion on materials.

Buffer

(1) An isolating circuit used to avoid reaction of a driven circuit on the corresponding driving circuit.

(2) A storage device used to compensate for a difference in rate of flow of information, or time of occurrence of events when transmitting information from one device to another.

Buffer Amplifier

One or more stages of RF amplification used in a transmitter to build up the control crystal frequency to an appropriate level before modulation. This is to prevent feedback of undesired frequencies to the crystal.

Buffer Condenser

Any condenser connected in an electronic circuit for the purpose of reducing peak or surge voltage amplitude to protect other parts in the same or following circuits.

Buffer Stage

An amplifier stage used to prevent feedback of energy from a power stage to a preceding stage.

Burner Drag

Total drag due to the presence of a missiles propulsive system; usually includes the drag forces on the igniter, flame holders, diffuser wall, combustion chamber wall, etc.

Burning Rate, Erosive

The increase in burning rate, over normal conditions which is incident to the sweep of gases over a burning propellant surface.

Burning Rate, Linear

The rate at which a solid propellant burns normal to its surface under design combustion chamber pressure. The burning rate is in accordance with Muraour's relationship. (See Fig. 7.5.1, p. 290)

Burnout
The end of combustion in a rocket. (See Brennschluss)

Burnout Point
The point on the missile trajectory at which the fuel supply of a specified rocket engine (booster, sustainer, or vernier) is cut off.

Burnout Velocity
The velocity of a rocket, rocket-powered aircraft, or rocket-powered projectile when fuel combustion terminates.

Burnout Weight
The weight of a missile at the time usable fuel supply is exhausted, but including any residual, unusable fuel.

Burst
(1) The explosion of a warhead
(2) Rupture of a solid propellant rocket case incident to excessive combustion pressure.

Buzz
(See Diffuser Buzz; Dither)

By-pass Capacitor
A capacitor used to provide a low-impedance path for radio or audio signals around a resistor or between a circuit terminal and ground.

By-pass Engine
A gas-turbine reaction propulsion engine, incorporating an air by-pass duct, to produce high thrust without excessive jet-stream velocities and give low specific fuel consumption.

C

C_L
(See Lift Coefficient)

C Band
A radio frequency band of 3.9-612 kilomegacycles with wavelengths of 11.8 cm to 7.3 cm. It includes the top two side bands of $S_{(Z)}$ through bottom three side bands of $X_{(Y)}$.

CEP
(See Circular Error Probable)

CFE
Contractor Furnished Equipment, or parts.

CPE
(See Circular Error Probable)

CPFF
Cost-Plus-Fixed-Fee.

CRT
(See Cathode Ray Tube)

CYTAC
A system of determining hyperbolic lines of position by measuring the time relationship between two synchronized radio signals. CYTAC is similar to LORAN in principle but capable of greater accuracy and has a greater range of operation since it utilizes only the ground wave at 100 Kcs. Cycle matching is used for maximum accuracy.

Cage
To lock the gyroscope of a gyro-controlled instrument in a fixed position with reference to its case.

Caliber
(1) The outside diameter of a projectile.
(2) In guns, the length in terms of a projectile diameter.

Canard Configuration
A type of airframe in which the control surfaces are small and well forward of the body, while the main lifting surfaces are rigidly attached in the aft region of the body. Lift is obtained by increasing the angle of attack of the body-wing combination by means of the forward control surface.

Can Combustor
(See Combustor, Can)

Canister
A protective container for housing a missile system, subsystem, or component, usually a pressurized cylindrical can.

Cannibalization
A maintenance modification or repair method in which the required parts are removed from a similar missile or assembly for installation on another. Sometimes used in lieu of formal spare parts provisioning.

Canted Nozzle
A scheme used in solid rocket metal parts design to permit directing the thrust vector at a desired angle to the axis of the cant. (Nozzle cant angles are usually limited to a maximum of 30° and more typically to 15° because of loss in impulse and local heating problems).

Capacitance, Acoustical

In an acoustical system, that coefficient which, when multiplied by 2π times the frequency, is the reciprocal negative imaginary part of the acoustical impedance. The unit is centimeters to the fifth power per dyne.

Capacitance, Electrical

In an electrical system, that coefficient which, when multiplied by 2π times the frequency is the reciprocal of the negative imaginary part of the electrical impedance. The unit is the abfarad.

Capacitor

A radio part consisting of two conducting surfaces separated from each other by an insulating material such as air, oil, paper, glass, mica or ceramic. A capacitor is capable of storing electrical energy. In radio circuits, capacitors are used to block direct current while allowing alternating and pulsating currents to pass. The capacitance of a capacitor is specified in microfarads and micro-microfarads. The capacitance of a parallel plate capacitor in air is equal to the area of the dielectric divided by 4π times the thickness of the dielectric. (Also termed Condenser)

Captive Flight

A flight wherein a guided missile, or component thereof, is carried on an aircraft in order to test the item under flight conditions. A test in which the test article has some freedom for functioning but with restraints that permit reuse of the missile.

Captive (Ground) Test

A technique of operating a missile on a test stand to determine or check its performance. Engines can be operated to full thrust and all conditions except those caused by actual flight can be simulated. (Also termed static test).

Capture

(1) In nucleonics, a process in which a nucleus acquires an additional particle.

(2) In launching, the process in which a missile having achieved flight speed is taken under control by the guidance system.

Capture Maneuver

(See Maneuver, Capture)

Cardan-mounted

A gimbal mounting system for a device requiring freedom of movement in one, two or three degrees.

Carrier Frequency

(See Frequency, Carrier)

Cascade Control

An automatic control system in which the control units, linked in chain fashion, feed into one another in succession, each regulating the operation of the next in line. (Sometimes termed piggy-back control).

Case Bonded Grain

(See Grain, Case Bonded)

Cassegrainian Mirror (or Lens)

A mirror mounted between the surface of a spherical (or parabolic) mirror and its focus. The purpose is to project the image formed by the outer portion of the incident rays. Named after Cassegrain, the astronomer, who invented it.

Casualty

(1) A casualty is an individual who is unable to discharge his primary duties. An individual who can be cared for by the unit medical support and returned to duty is not considered a casualty.

(2) A event of adverse consequences, (e.g., premature explosion).

Catapult

A fixed structure which accelerates a missile or aircraft. It must combine the function of directing and accelerating the missile during its travel on the catapult; serves the same function for a missile as does a gun tube for a shell. (See Launcher)

Cathode Follower

A circuit in which the output load is connected in the cathode circuit of an electron tube, and the input is applied between the control grid and the remote end of the cathode load. The circuit is characterized by low output impedance, high input impedance, gain less than unity under most operating conditions, and an output voltage nearly independent of the current taken from the output terminals.

Cathode Ray Tube (CRT)

A means of visually displaying electrical intelligence. An electron beam impinges on a fluorescent screen. This beam can be deflected in a vertical and horizontal plane by deflecting plates with electrical potentials which vary with the intelligence it is desired to display. The intensity of the beam can be similarly varied by the accelerating potential applied to the electrons. Because of the low inertia of electrons, an oscillograph using a CRT has an extremely fast response time (in the microsecond range) which is limited only by mechanical considerations such as screen intensity and film recording.

Cavitation

The formation and collapse of vapor pressure bubbles due to the movement of a body through a fluid, or the effect of this action.

Cavity Resonator

(See Klystron)

Celestial Navigation

(See Navigation, Celestial)

Celestial Radio Tracking

A navigation technique wherein the microwave emanations of the sun, moon or certain stars are used to ascertain their positions with reference to the point of observation.

Center of Gravity

(See Center of Mass)

Center of Mass

The point at which all the mass of a body may be regarded as being concentrated, insofar as motion of translation is concerned. Commonly termed Center of Gravity.

Center of Percussion

In a rotating body, the point on a line passing through the center of rotation and the center of gravity at which force can be applied at a right angle to this line without causing a reaction at the center of rotation. The location of the center of percussion is expressed as the square of the radius of gyration divided by the distance between the center of gravity and the center of rotation.

Center-of-Pressure

The point on an airfoil at which the resultant of all aerodynamic forces apparently operates. (Two-dimensional airfoils) - at supersonic speeds slightly ahead of the midchord point, depending on the Mach number, thickness ratio, and type of cross-section. For a flat plate of zero thickness and infinite aspect ratio, the center of pressure is at the midchord.

Center of Pressure Coefficient

With respect to an aerodynamic lifting surface (airfoil), the ratio of the distance of the center of pressure from the leading edge of an airfoil to the chord length.

Center of Pressure (of an Airfoil)

The intersection of the chord of an airfoil (prolonged if necessary) and the line of action of the resultant of air forces.

Centrifugal Compressor (Radial Compressor)

An air compressor which imparts high kinetic energy to air in the form of centrifugal or radial air flows. A large proportion of the kinetic energy is subsequently converted into pressure potential energy in a diffuser system.

Centrifugal Force

The force which a rotating mass imposes upon the device which restrains it.

$$F_c = m\omega^2 r$$

where m = mass

$\omega = 2\pi$

r = radius

Ceramel (Ceramet)

A ceramic-coated metal.

Certified Component

A component (part, assembly) which has successfully passed a limited number of critical performance and environmental tests.

Chaff

Electromagnetic-radiation reflectors in the form of narrow metallic strips used to create radar echoes for confusion of enemy radars. Chaff represents one type of confusion reflector. (See Reflector, Confusion)

Chain Reaction

A self-sustaining series of events. In a nuclear reaction, one in which neutrons essential to the reaction are produced by

the reaction in sufficient quantity to sustain or increase the reaction rate. Any chemical or nuclear process in which some of the products of the process are instrumental in the continuation of the process.

Chance Failure

(See Failure Modes)

Channel, Telemeter

A term which designates the complete route for transmission of a telemetered function, including pick-up, commutator, modulator, transmitter, receiver, demodulator, decoder, and recorder. A single source or channel of information.

Channelized

A term pertaining to training, implying that a considerable amount of knowledge and skill peculiar to the equipment is required.

Characteristic Length, L* (Rocket)

In propulsion, the ratio of the chamber volume to its nozzle throat area, L*. A measure of the length of travel available for the combustion of the propellants. To obtain the best performance possible the chemical reaction should be completed before the gaseous combustion products reach the entrance to the exhaust nozzle. The objective is to minimize L* without introducing any significant reduction in the measured value of characteristic velocity due to incomplete reaction of the propellants. (See Eq. 7.6.11 and Fig. 7.6.1)

Characteristic Velocity (c*)

A measure of the effectiveness with which the chemical reaction of the propellants in the rocket motor produce the high-temperature, high-pressure gases. (See Eq. 7.4.7, p. 287)

Characterization Device

A device which adds or subtracts a value to a control signal in some predetermined relationship.

Charge, Propellant

The solid stage oxidizer and fuel used in solid propellant rockets. The charge usually includes the inhibitor which does not contribute to the total impulse. (See Fig. 10.52, p. 479)

Charge/Weight Ratio

A term used in solid rocket design to ratio the weight of the propellant charge including the inhibiter to the total weight of the solid rocket (charge and metal parts) excluding special fittings and attachments. (See Metal Parts/Weight Ratio)

Checkout

A test or procedure for determining whether a person or device is capable of performing a required operation or function. When used in connection with equipment, a checkout usually consists of the application of a series of operational and calibrational tests in a certain sequence, with the requirement that the response of the device to each of these tests be within a predetermined tolerance. For personnel, the term checkout is sometimes used in the sense of a briefing or explanation to the person involved, rather than a test of that person's capabilities.

Chemical Milling

The controlled removal of metal by masking the part to be treated, then immersing it in an acid or alkaline etching bath at a controlled temperature for a carefully timed period. The process may be used on sheet, forgings or extrusions.

Chemosphere

That part of the atmosphere extending from 20 to 50 miles in altitude.

Chopper

Any device for periodically interrupting a continuous current or flux.

Chuffing (Chugging) (Cumbustion Resonance)

The characteristic of certain rockets to burn intermittently with relatively low frequency pressure oscillations and with an irregular puffing noise.

Chugging

(See Chuffing)

Circle of Confusion

In an optical system the circular image of a distant point object as formed in a focal plane by a lens.

Circular Error Probable (CEP) Also Circular Probable Error (CPE)

A term describing the hitting accuracy of a guided missile measured at the target in a plane perpendicular to the trajectory for air targets and in the ground plane for

surface targets. Thus, it is that error which is just as likely to be exceeded as not. It is the radius of a circle that encompasses 50% of the probable points of impact.

Circular Probable Error (CEP)
(See Circular Error Probable).

Circumplanetary Orbit
(See Orbit, Circumplanetary)

Circumsolar Orbit
(See Orbit, Circumsolar)

Cislunar Space
(See Space, Cislunar)

Cisplanetary Space
(See Space, Cisplanetary)

Classification of Defects
A method of establishing acceptability of a product. The classification establishes need for rework or changes to meet a specification.

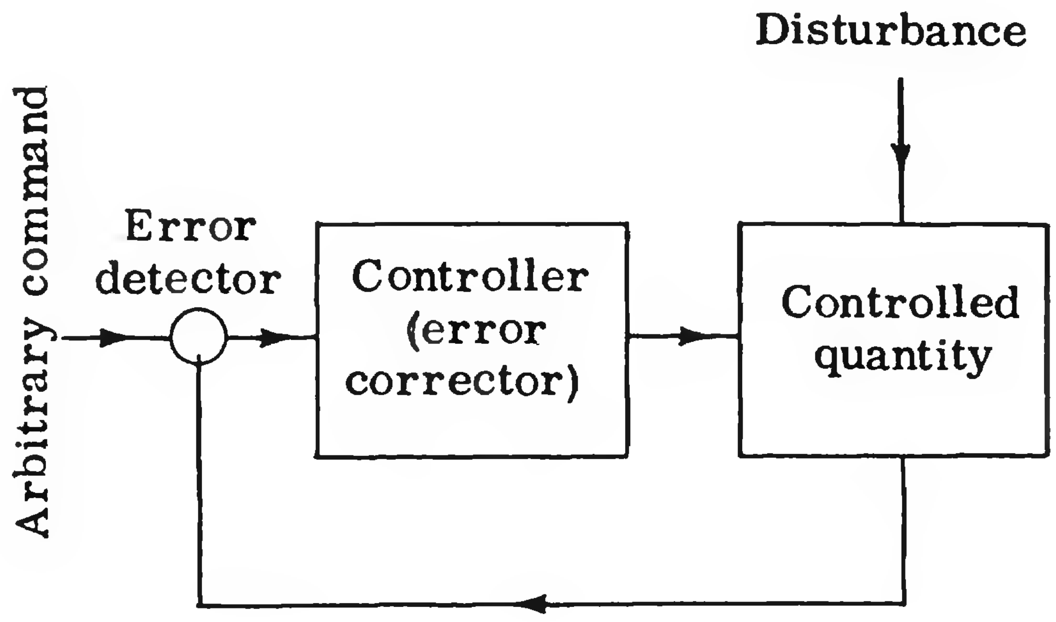
Classified
A security term applied to material or information whose disclosure to a prospective enemy would be inimical to the national interests.

Climatic Test
A generic term describing any test designed to evaluate the ability of equipment to survive climatic conditions. Climatic tests usually include: sunshine, rain, hail, snow, sleet, wind, humidity, aridity, sand, dust, temperature, fungus, salt spray, etc.

Clipping
(1) Distortion in amplifiers produced by flattening of plate current curve due to excessive grid current during positive grid swing.
(2) Distortion in the A.F. component of a modulated wave when modulation amplitude exceeds that which brings the trough to zero.
(3) Generation of approximately square waves by shunting biased diodes across the load, the bias determining the amplitude at which the peaks are to be clipped.

Closed Loop
A family of automatic control units linked together with a process to form an endless chain. The effects of control action are constantly measured so that

FIG. 10.12 BASIC ELEMENTS OF A CLOSED LOOP SYSTEM



if the controlled quantity departs from the norm, the control units act to bring it back. (See Fig. 10.12)

Closed Loop Testing
A test technique in which all dynamic elements of the missile system, including the guidance and aerodynamic characteristics, are physically used or simulated with all loops closed as in flight.

Closed Orbit
(See Orbit, Closed)

Cluster
A grouping together of solid or liquid rocket engines to provide a launching carriage or booster assembly.

Cluster Missile
(See Missile, Parallel Cluster)

Clutter, Radar
The visual evidence on the radar indicator screen of sea-return or ground return which, if not of particular interest, tends to obscure the target indication.

Coaxial Line
An electrical cable having concentric conductors. Used as a transmission line for audio, radio, radar, and television signals.

Code Name
A generic code name assigned to each guided missile to permit convenient reference to it in unclassified correspondence and oral discussions. (e. g., Nike, Talos, Atlas, Bomarc)

Coherent Carrier
A basic system referring to the principle involved in any transponder system, i.e., interdependence of a transmitter and receiver. e. g., in the Dovap system, the

missile is interrogated and after the carrier is received it is retransmitted at a definite multiple frequency for comparison.

Cold Room

An environmental test chamber used to provide a low temperature area for evaluating equipment in this regime.

"Cold Tests" of Resonant Systems

The testing of a microwave system with the tube in place, but in a nonoperative condition so that its electronic admittance is zero. The resonance frequency, loaded and unloaded Q, and the driving point admittance are quantities usually measured.

Collapse

The destruction of a target by crushing due to external pressure from a blast (implosion).

Collimation

The process of adjusting an instrument or device so that its reference axis is aligned in a desired direction within a predetermined tolerance.

Combustion

In propulsion, an exothermic chemical process usually producing high temperature exhaust gases and light. Oxidation is generally involved. The process is slow compared to a chemical or nuclear explosion.

Combustion Resonance

(See Chuffing)

Combustor, Can

A type of ramjet or turbojet engine combustor resembling a conically shaped, perforated "can". Usually has a separate assembly for the pilot stage.

Comet Orbit

(See Orbit, Comet)

Command Control Center

A central station of an air defense system wherein information on enemy and friendly forces is collected and analyzed and appropriate commands are issued.

Command-Destruct Signal

A radio signal used intentionally to operated the destruction device carried in a missile.

Command Guidance

(See Guidance, Command)

Command Guidance System

A system of missile control wherein intelligence transmitted to the missile from an outside source causes the missile to traverse a directed path in space. Missile command guidance systems in general require that the behavior of the missile (and of the target, if it is in motion) be monitored externally so that any deviation from a prescribed collision course may be computed, and the deviation communicated to the missile and interpreted by its control system so as to realign the missile flight path toward an intercept with the target. (See Fig. 10.13)

Command Post

The place from which a commander exercises his command function. Normally, each launch station and guidance station will have a command post.

Commutation

(See Multiplexing)

Compensated Amplifier

A broad band amplifier in which the range is extended by choice of tubes and by slight resonant effects. Used as video amplifiers.

Complete Round

(See Round)

Compliance

In a mechanical system a measure of its responsiveness to a periodic force; it is that coefficient which, when multiplied by 2π times the frequency, is the reciprocal of the negative imaginary part of the mechanical rectilineal impedance. The unit is the centimeter per dyne. (See Compliance, Mechanical; Impedance, Mechanical Rectilineal)

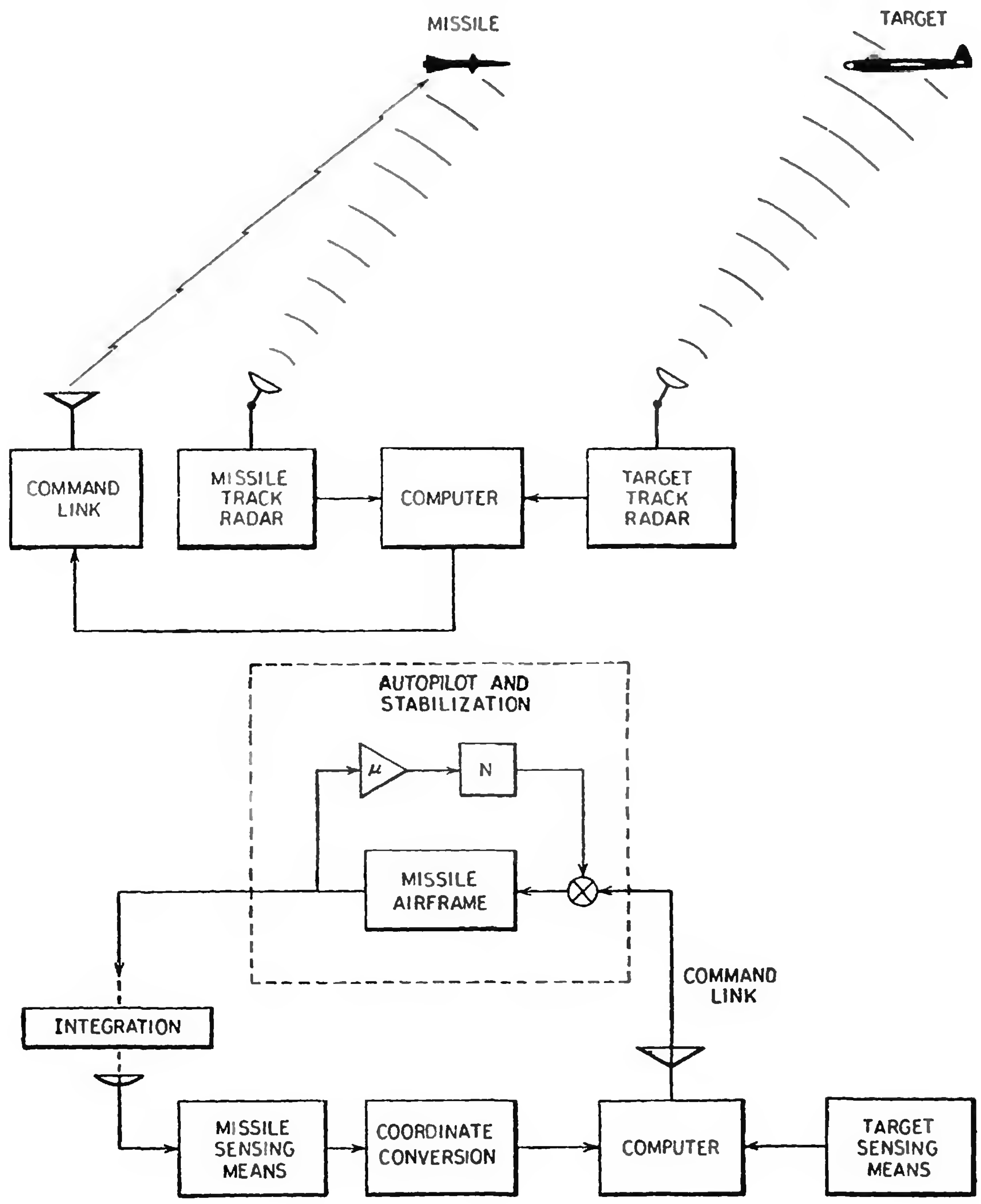
Compliance, Mechanical

Compliance in a mechanical vibrating system is that coefficient which, when multiplied by 2π times the frequency, is the reciprocal of the negative imaginary part of the mechanical impedance. The unit is the centimeter per dyne. (See Compliance)

Compliance, Rotational

In a mechanical rotational system a measure of its responsiveness to periodic torque; it is that coefficient which, when multiplied by 2π times the fre-

FIG. 10.13 GENERALIZED COMMAND GUIDANCE SYSTEM



quency, is the reciprocal of the negative imaginary part of the mechanical rotational impedance. The unit is the radian per centimeter per dyne. (See Impedance, Mechanical Rotational)

Component
A group of parts united to perform a certain function. A component is not self-sufficient, but depends upon other components to accomplish a given task. (e.g., gyroscope, accelerometer, amplifier, receiver.)

Component, Certified
(See Certified Component)

Component Part
An item not normally subject to further disassembly. e.g., resistors, capacitors, tubes, potted or molded items, etc.

Composite Propellant
(See Propellant, Composite)

Component, Qualified
(See Qualified Component)

Compressive Waves
(See Shock Wave)

Computer
A term applied to calculating machines ranging from the Chinese abacus to electronic "brains". In automation, it refers to machines which, once set up, perform a series of individual computations without outside tutoring.

Computer, Analog
(See Analog Computer)

Computer, Digital
(See Digital Computer)

Computer, Spherical-Trigonometric
A computer capable of converting distance traveled into corresponding changes in latitude and longitude for the particular latitude of the missile.

Condensation Trail (Contrail)
A visible trail of small water droplets or ice crystals formed under

certain conditions in the wake of an aircraft or missile.

Condenser

(See Capacitor)

Condenser, Buffer

(See Buffer Capacitor)

Condenser, By-Pass

(See By-Pass Capacitor)

Confidence Coefficient

(See Confidence Level)

Confidence Interval

A statistical term establishing the difference between the upper and lower confidence limits.

Confidence Level (Confidence Coefficient)

The percentage of statements, tests, etc. expected to be correct. The certainty with which data from a small group applies to a specific confidence interval. Use is made of appropriate data and a selected confidence level (e.g., at a 95% confidence level, the conclusions drawn will be in error only one time in twenty—on the average).

Confidence Limits

The computed upper and lower limits of the desired value of a physical quantity.

Configuration

The physical nature of an item. The physical arrangement of components which comprise a guided missile and the latter's dimensions.

Conformal Mapping

A method of diagrammatically representing the performance of a servo system. Consider first the loop transfer function Y_0 (s), where in general s is a complex number of the form s $s = \alpha + j\omega$. Corresponding to each value of s there is particular value of Y_0 (s). This can be shown by showing the value of s as a point in a complex plane called the s plane, and the corresponding value of Y_0 (s) as a point on another complex plane, called Y_0 plane. Corresponding to a contour in the s plane there is a contour in the Y_0 plane The shape of the latter depends on the function Y_0 (s) and hence on the parameters of the servo it represents. Thus, if the s plane is divided into a net of lines of constant α and constant ω, parallel to the axes, there is a corresponding pattern of lines in the Y_0 plane.

Conformal Projection

A mapping system wherein a surface in a given coordinate system is mapped or transformed into an alternate reference system without change in the angular relationship between any two points.

Conical Scanning

A radar scanning system wherein a point on the radar beam describes a circle at the base of a cone, and the axis is the generatrix of the cone.

Conic Orbit

(See Orbit, Conic)

Constant-Bearing Course

That missile trajectory wherein the line-of-sight from the missile to the target maintains a constant direction in space.

Constant-Bearing Navigation

(See Navigation, Constant Bearing)

Constant M Control

A method of controlling a missile power plant in which the Mach number M rather than the velocity is held constant. It is sufficient to measure ram air pressure, static air pressure and to provide a solution to the equation to keep M constant

$$\frac{Po_2}{P} = 1.2M^2 \left(\frac{7.2M_1^2}{M_1^2 - 1}\right)^{2.5} \text{ for air}$$

Constant M is used because of the ease of measurements required for control and because most other parameters are a function of M rather than velocity. (See Mach Meter)

Constant Velocity Control

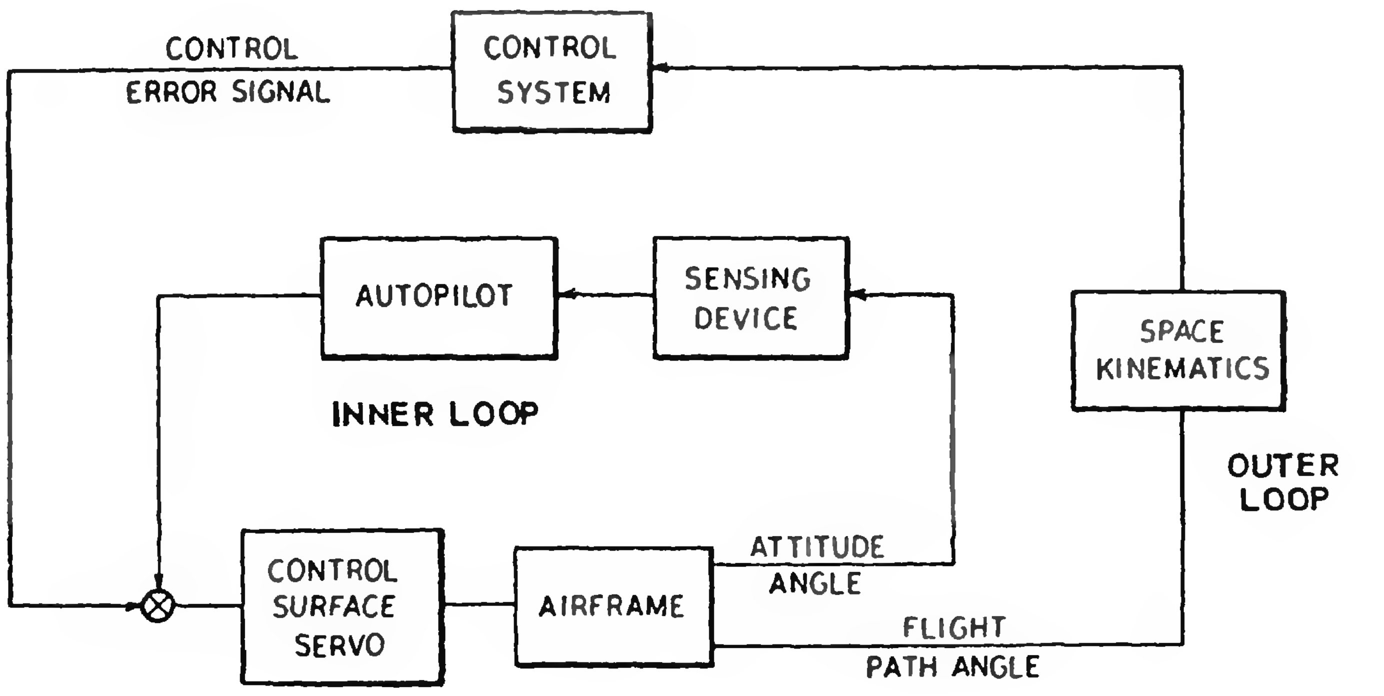
A method of controlling a missile power plant to maintain constant velocity rather than constant Mach number. It is necessary and sufficient to measure raw air pressure, static pressure and air temperature to establish the proper thrust control.

Constant velocity control is used to avoid the need for a present position indicator, velocity and time being used in computing range.

Consumer's Risk

The probability or risk of accepting a lot, for a given lot quality or process quality, whichever is applicable. Usually

FIG. 10.14 CONTROL SYSTEM CONFIGURATION



applied only to quality values that are relatively poor.

Contact Fuze

A device which initiates warhead detonation after some interval of time following impact with a target surface.

Contamination

The deposit of radioactive materials, such as fission fragments or radiological warfare agents, on any objective or surface which makes it hazardous.

Continuous Wave, Interrupted (ICW)

A continuous wave that is interrupted at a constant audio-frequency rate.

Continuous Wave Radar

(See Radar, Continuous Wave)

Contrails

(See Condensation Trail)

Contra-Injection

In a jet engine the injection of fuel into the air stream in a direction opposite to the flow of air.

Control

As related to a missile, the process of stabilizing the missile with respect to disturbances (such as gusts of wind) while simultaneously furnishing satisfactory responses to guidance signals.

Control, Bang-Bang

A control method wherein the corrective control applied to the missile is always applied to the full extent of servo motion.

Control Center

The facility from which command is exercised over a group of missile launch complexes.

Controllability

The ability of a missile or aircraft satisfactorily to control its maneuvers in response to guidance intelligence.

Controlled Temperature Cabinet

An environmental test facility with automatic control accessories for testing ability of equipment to withstand high or low temperatures, temperature shocks and cycling. Sometimes includes humidity test provisions.

Control Point

In automation the value of the controlled variable which, at any instant, the automatic controller operates to maintain.

Control, Proportional

Control in which the corrective control applied to the missile is made proportional to the error signal.

Control System

(1) A coordinated group of components designed to exert a directing influence on other components. The system for properly maneuvering a missile in response to guidance intelligence; this usually includes an autopilot, servos and control surfaces or jets. (See Fig. 10.14)

(2) A group of control consoles, housed in the blockhouse, that monitor and launch the missile utilizing radio and electronic control devices. (See Control System, Automatic; Control System, Flight)

Control System, Automatic

Any operable combination of one or more automatic controls connected in closed loops with one or more processes. (See Fig. 10.6, p. 418)

Control System, Flight (Ballistic Missile)

The flight control system has three functions. The primary function is to

maintain missile stability about the pitch, roll, and yaw axes. The second function is to receive command signals from the guidance system and convert these signals into mechanical movements of the engines to change the missile course. The third function is to turn (pitch) the missile onto the proper target heading in the early moments of flight.

Convection

Motions resulting within a fluid owing to differences in temperature and density.

Conversion Kit

A modification kit used to change a system for improved performance, modernization, reliability, etc. The kit is usually complete in every detail and may be used in the factory or field. The makeup of the kit may be different for these uses.

Converter

That section of a superheterodyne radio receiver which changes incoming modulated r.f. signals to a lower frequency known as the intermediate frequency; the converter section includes the oscillator and the first detector. Also, a device, usually rotary, changing electrical energy from one form to another, as AC to DC, etc.

Converter Frequency

Any circuit or device that accomplishes a frequency conversion, as for example the mixer detector of a superheterodyne. Also an arc tube, a motor generator.

Converting

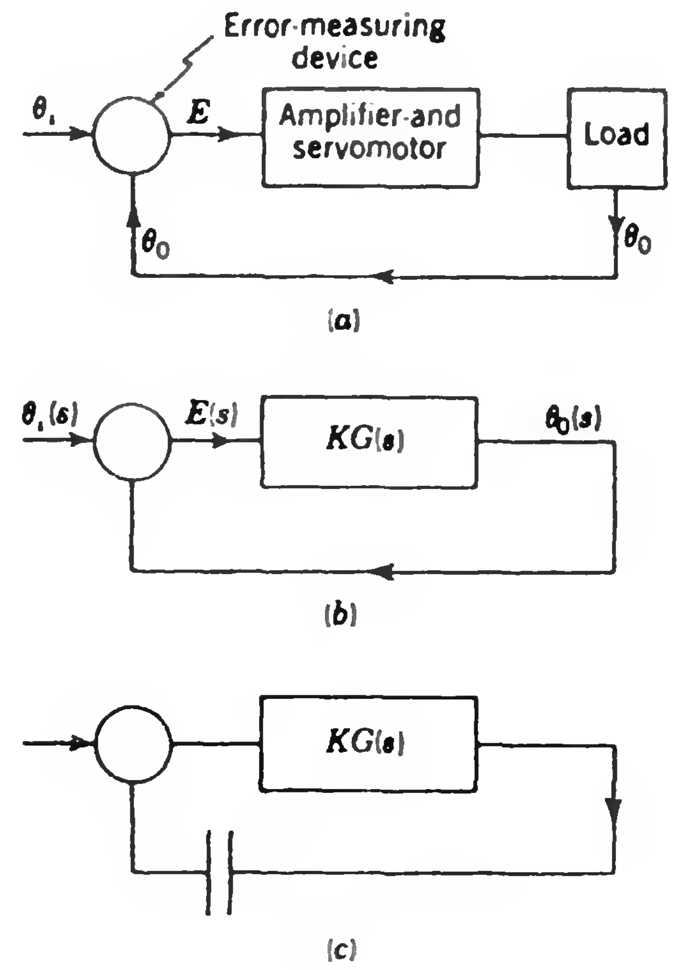
(1) In nucleonics, the process whereby neutrons are used to transmute thorium -232 into uranium -233 or uranium -238 into plutonium -239. Less specific than breeding.

(2) In electrical parlance, changing from one type of power to another (AC to DC) or from one type of signal to another (AM to FM).

"Cookie-Cutter" Intake

A normal shock intake for a ramjet engine; a sharp edged intake for any air breathing engine. (See Fig. 10.17)

FIG. 10.6 A SYSTEM LOOP, CLOSED AND OPENED



Cooldown

The process of reducing the temperature of containers and associated piping for cryogenic materials (e.g., lox, liquid nitrogen) to reduce thermal shock and boiloff by flowing lox or liquid nitrogen through the container and allowing it to vaporize or boiloff, thereby absorbing heat from the container to reduce its temperature.

Cooling Film

A cooling technique where a liquid is admitted through small holes into a jet or rocket engine combustion chamber or nozzle of a rocket near possible hot spots. Cooling is by evaporation of the liquid film.

Cooling, Regenerative

A cooling technique where a liquid is circulated through a jacket-enclosed combustion chamber of a rocket. The rocket fuel is often so used prior to its combustion.

Cooling, Sweat

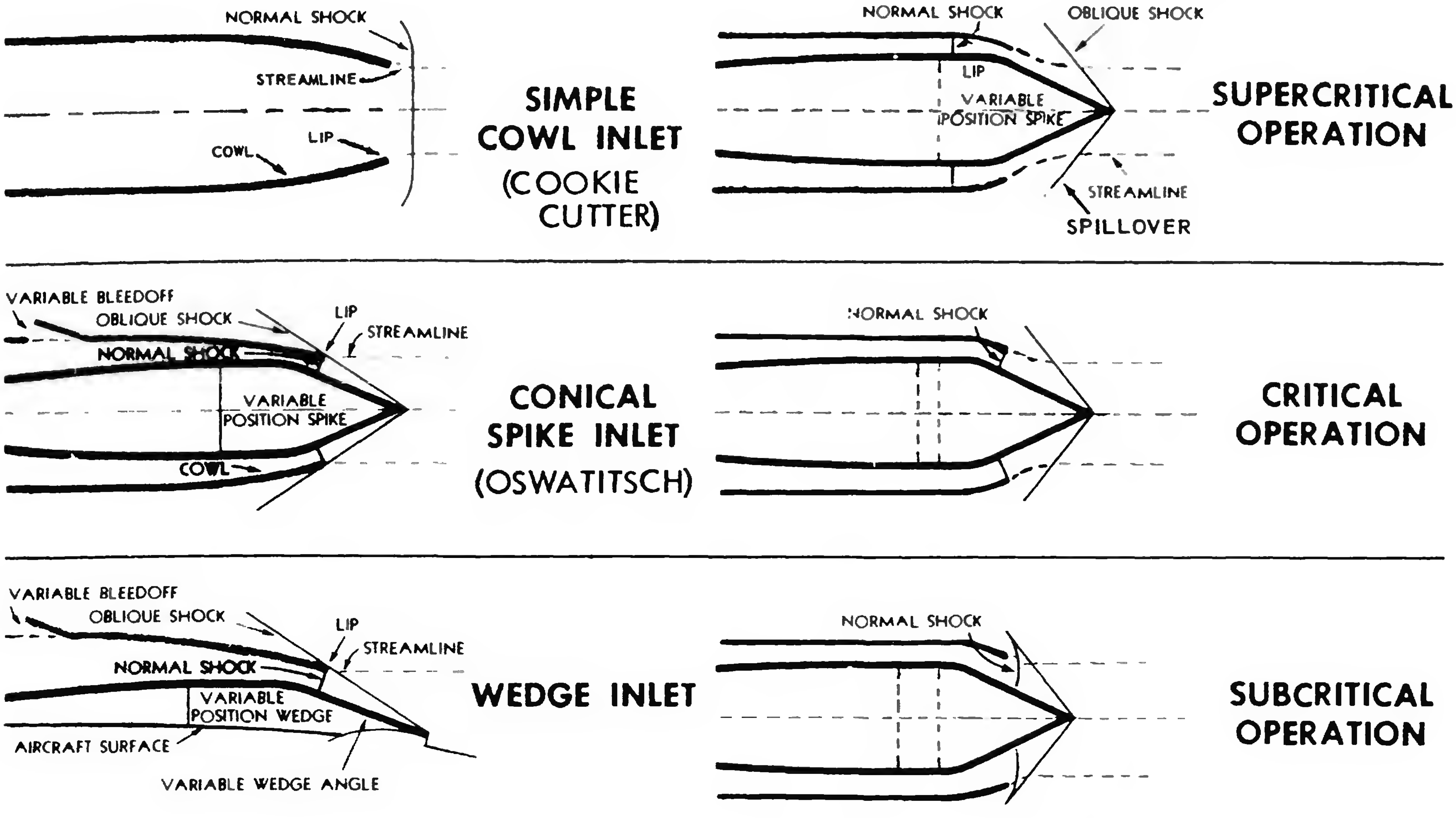
A cooling film technique employing a porous chamber wall through which a liquid slowly flows. Cooling is by evaporation of the liquid or by conduction or both.

Cooperative Systems (Instrumentation)

Instrumentation systems which require transmission of information from a ground station (remote) to the missile

FIG. 10.15

SUPERSONIC INLET DIFFUSERS — SUPERSONIC DIFFUSER OPERATION



in flight; processing of the information by the missile borne equipment and re-transmission of the processed data to the originating and/or other remote ground stations. (e.g., Azusa, Dovap).

Coordinated Tooling

Tooling used to insure the matching of equipment or assemblies, usually from two sources of supply. Coordinated, or master, tooling provides assurance that parts or assemblies which fit the tools will fit with each other.

Cordite

A colloidal rocket propellant composed of guncotton, nitroglycerin and mineral jelly, mixed and formed with the aid of solvents.

Coriolis Acceleration

When the apparent acceleration of a freely falling body relative to the earth is considered, an additional acceleration is involved, resulting in an eastward deviation x of a falling body.

$$x = \frac{1}{3}\,\omega g t^3 \cos\phi = \frac{1}{3}\,\omega\sqrt{\frac{8h^3}{g}}\cos\phi$$

where ω = rot. vel. of earth
g = effective gravity
t = time of fall
ϕ = latitude
x = eastward distance
h = height of fall

For a vertically projected body:

$$x = \frac{4}{3}\,\omega g t^3 \cos\phi$$

Horizontal deviating acceleration (experienced by a missile in horizontal flight):

$$y = 2\omega\nu \sin\phi$$

where ν = horizontal velocity of the missile

Note that the sign of the Coriolis acceleration changes when the equator is crossed.

Corner Reflector

A device used to increase the effective radar cross section of a target. (See Fig. 6.23, p. 257)

Correction Maneuver

(See Maneuver, Correction)

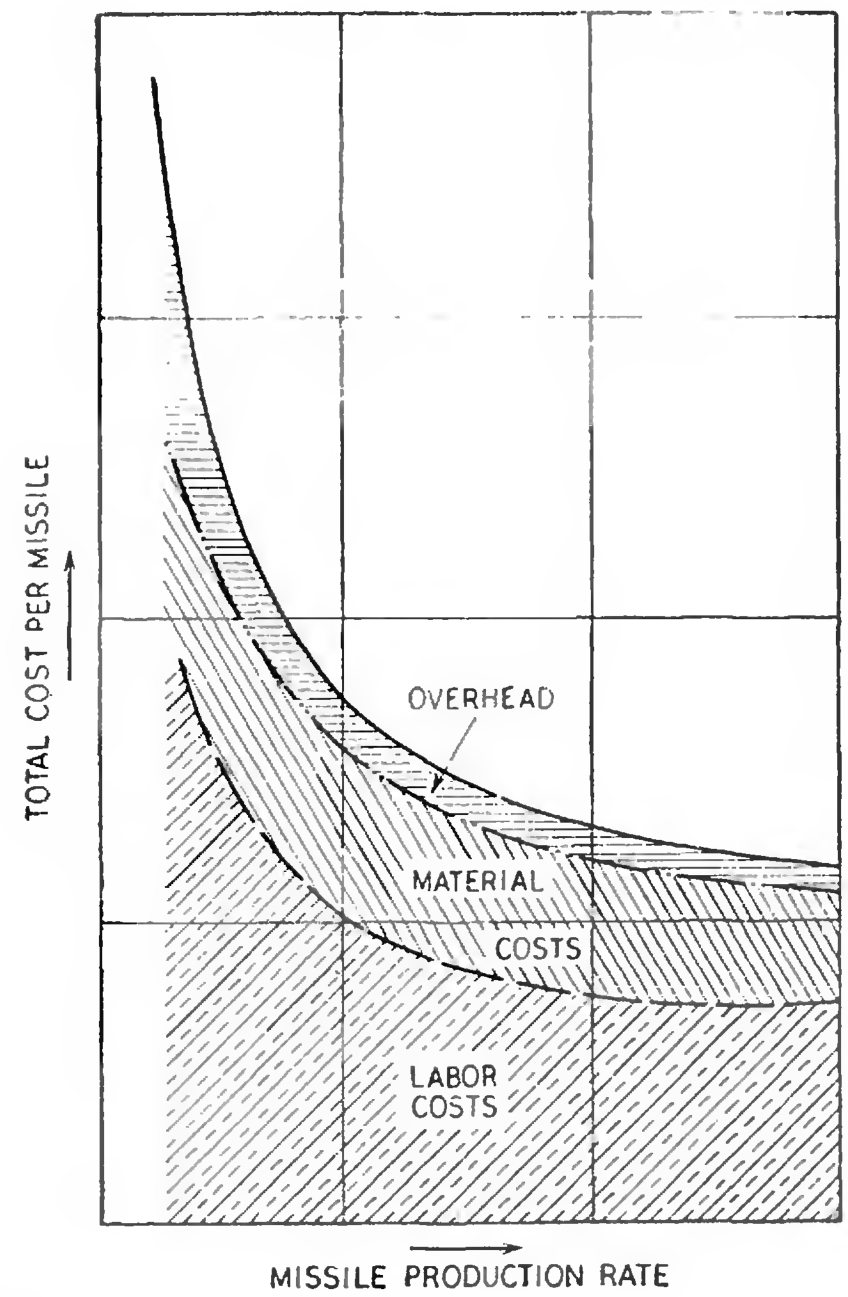
Correlation Coefficient

A statistical coefficient P which is

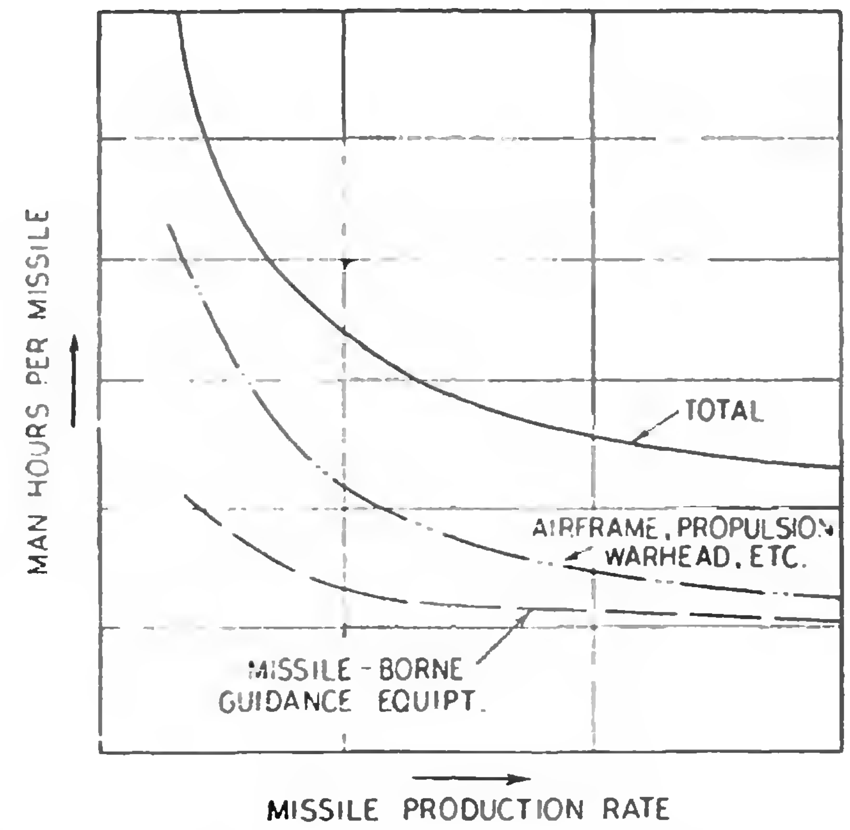
$$P = \frac{(X-M_x)\ (Y-M_y)}{\sigma\ x\ \sigma y}$$

a measure of the dependency or correlation between X and Y in a normal

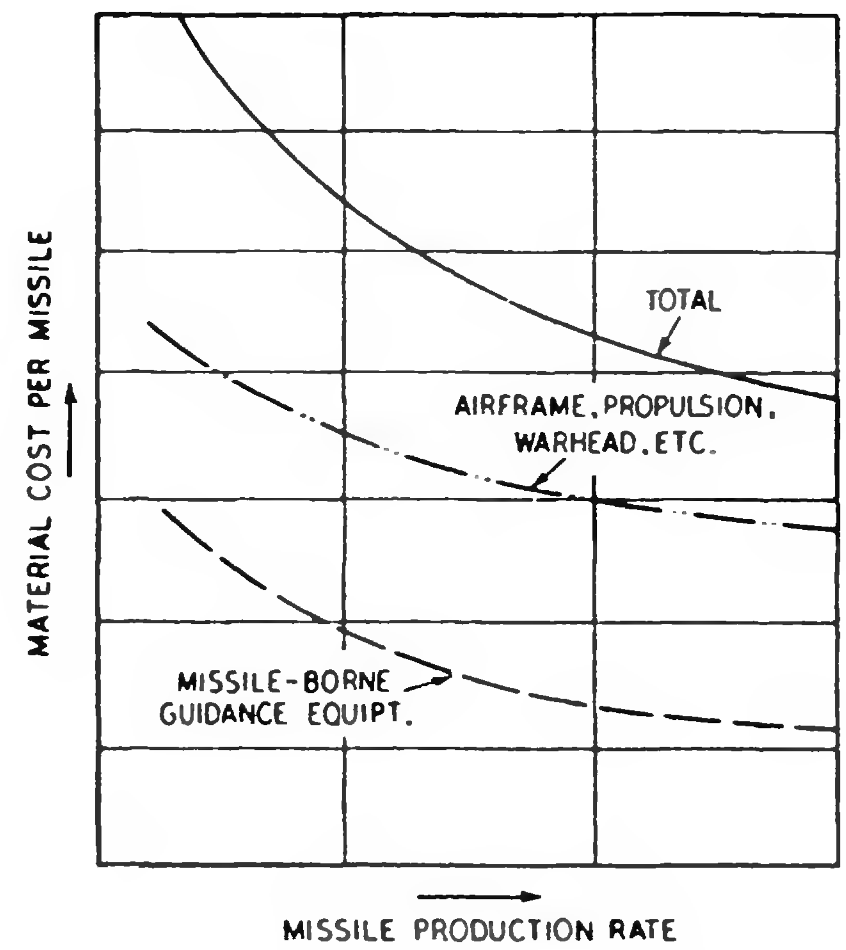
FIG. 10.15A COST RELATIONS IN MISSLE PRODUCTION



(a) General Relationship between Total Cost per Missile and Production Rate.



(b) General Relationship between Man Hours per Missile and Missile Production Rate.



(c) General Relationship between Material Cost per Missile and Missile Production Rate.

distribution; P = 0 implies that X and y are independent.

Corrosion Test

A test designed to determine the degree of adequacy of a part for withstanding corrosion. Usually a salt spray test is used.

Cosmic Rays

Rays of extremely high penetrating power. These rays are thought to be produced beyond the earth's atmosphere by transmutations of atoms continually taking place through interstellar space.

Cosmonautics

The science of space flight and travel in interstellar regions. (See Astronautics)

Cost

Cumulative average cost for number of units produced:

$$C = C_1 N^P$$

Used to estimate break-even points and to check estimated total production costs. (See Fig. 10.15A)

Cost

Unit cost for N units produced:

$$C_N = C_1 \ (N)^{P+1}$$

Cost

Unit cost for N units produced:

$$C_N = C_1(N - 1/2)^P \ (P + 1)$$

where C = Cost of unit
N = Number of units produced
C_1 = Cost of first unit

P = Slope of the learning curve (0.33 for 80 per cent learning curve)

C_N = Cost of Nth unit at N units

Cost-Plus-Fixed-Fee

A method of contracting in which the fee earned by the contractor is established as a certain percentage of the originally estimated cost. The contractor is paid for all of his work but the fee is increased only with an increase in scope of contract.

Cotar

A passive range instrumentation and/or safety system designed to provide position information by determining the angle between the remote ground based antenna system and a missile transmitter (telemetering or other) by a phase comparison technique. The system, developed by Cubic Corp., does not require a separate transponder.

Count-Down

The step-by-step process of a weapon system checkout and flight readying leading to missile launching; it is performed in accordance with a pre-designed time schedule and measured in terms of x - time.

The countdown usually is confined to the time from assembly at the test or loading area to the actual firing.

Countermeasures

That part of military science which by the employment of devices and/or techniques has as its objective the impairment of the operational effectiveness of enemy activity.

Countermeasures, Active Electronic

Electronic countermeasures involving actions taken which are of such nature that their employment is detectable by the enemy.

Countermeasures, Electronic

Electronic countermeasures refer to that major subdivision of the use of electronics which involve actions taken to reduce the effectiveness of enemy equipment and/or tactics employing or affected by electromagnetic radiation.

Countermeasures, Passive Electronic

Electronic countermeasures involving actions taken which are of such nature that their employment is not detectable by the enemy.

Coupled Modes (Principal Modes)

In mechanical systems two frequencies will be found where the amplitudes of the motion consisting of a combined rotation and translation are a maximum. These are called the coupled modes or principal modes and they may be calculated from the uncoupled modes.

The resonant frequencies thus determined are very near the natural frequencies of the system, and the deformation configurations are called the normal or principal modes of vibration.

Crater

The pit, depression, or cavity formed in the surface of the earth by an explosion. The nearer to the surface the detonation occurs the shallower the crater.

Crater Depth

The maximum depth of the crater measured vertically from the deepest point of the pit to the original ground level.

Crater Diameter

The average diameter of a crater measured at the level corresponding to the original surface of the ground.

Critical Damping

(See Damping, Critical)

Critical Damping Constant

(See Damping, Critical Constant)

Critical Mass or Size

In a fissionable material the amount of material which will just support a chain reaction power level. This is related, among other things, to the volume it occupies, or size.

Critical Materials

A general classification of raw and processed materials according to their strategic value, both in time of peace (stockpiling) and in time of war.

Critical Operation

A term which describes a limiting condition for ramjet operation. When the heat released by the burner is of such a magnitude that the back pressure at the exit to the subsonic diffuser causes the normal shock to be positioned at the inlet, then the operation is said to be critical.

Critical Temperature

That temperature above which a gas cannot be liquified by pressure alone. The pressure under which a substance may exist as a gas in equilibrium with the liquid at the critical temperature is the critical pressure.

Cross-Modulation

Modulation of a desired signal by an undesired signal.

Cross-Talk

The interference between nearby circuits, wherein signals in one circuit are undesirably reproduced in another, or other circuits.

Cross Wind

A wind which is at an angle to the flight path.

Cruciform Configuration

An aerodynamic configuration design in which the aerodynamic surfaces are identical and symmetrically located at right angles to each other around the missile body.

Cruciform Grain

A solid propellant rocket grain with a cruciform cross section. The grain is an external burning, partially restricted type. (See Fig. 10.16)

Cryogenics

The science of physical phenomena in the temperature range below about -50° C (-58°F). More generally, cryogenics, or its synonym cryogeny, refers also to methods of producing very low temperatures.

Cryogeny

The science of refrigeration.

Crystal Controlled Oscillator

(See Oscillator, Crystal Controlled)

Crystal Filter

A highly selective tuning circuit employing a quartz crystal, sometimes used in the i.f. amplifier of a communications receiver to improve selectivity so as to permit reception of a desired station even when there is strong interference from other stations on nearby channels.

Cumulus Clouds

Billowed heaps with flat bases and tufted tops. They have considerable shadow and often are very dark on the underside. Size and shape vary from flat small balls of cloud-cotton to great towers with valleys and ravines along the sides. The cloud is a low type, but can be found with bases from 500-1000 feet and tops as high as 20,000 feet. It is composed of water droplets and may produce rain if well developed. Flat, fair-weather types are known as cumulus humilis and the well-developed variety as cumulus congestus.

Curie

The number of nuclear disintegrations per second from a gram of radium (3.7×10^{10}) used as a unit of radioactivity.

Cutoff

The instant of cessation of thrust of a jet or rocket motor. (See Brennschluss)

C-W Doppler Radar

A radar which uses C-W as distinct from pulsed radiation and the Doppler shift to perform its function. If the target is stationary, its presence may be detected by rectifying the energy returned from the target and displaying it upon a d-c galvanometer. No other property of the target may be deduced except its presence and possibly its direction. If, however, the target is moving, its radial velocity also may be detected by comparing the echo frequency against the transmitted frequency. The echo radio frequency will differ from the transmitted frequency because of the Doppler effect. (See Doppler) (See also Figs. 10.17, p. 424, and 6.12, p. 245)

Cycle

One complete set of the recurrent values of a periodic quantity.

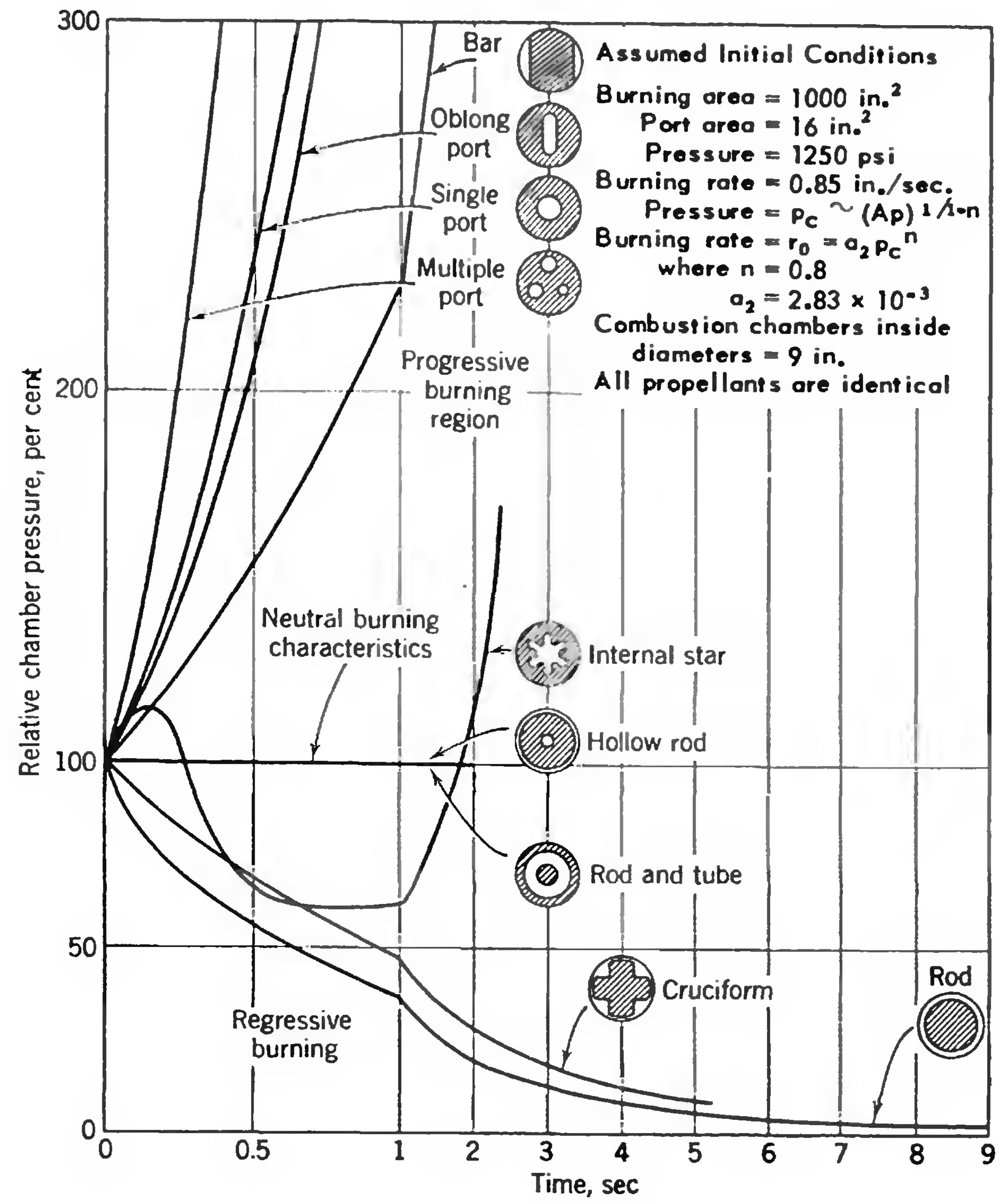
Cyclic Binary Code

(See Gray Code)

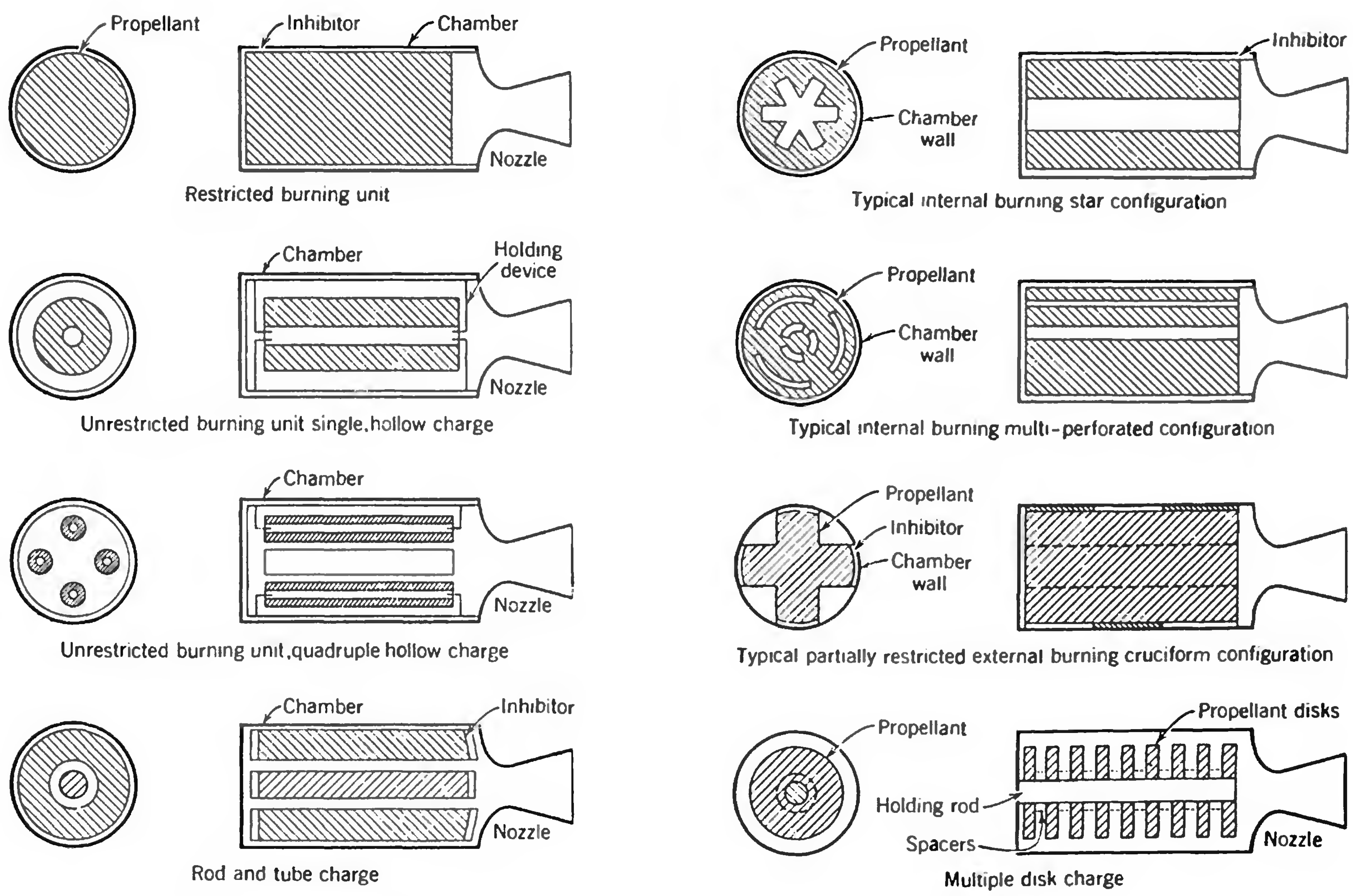
Cyclostrophic Wind

Winds which blow as a result of a pressure gradient and centrifugal force, but in the absence of Coriolis force. They are, of necessity, cyclonic and restricted to equatorial zones which is the only place Coriolis force is zero. The cyclostrophic component of a wind is the difference between the gradient and the geostrophic winds. Hurricanes are

FIG. 10.16 CHARACTERISTICS OF SOLID PROPELLANT GRAINS



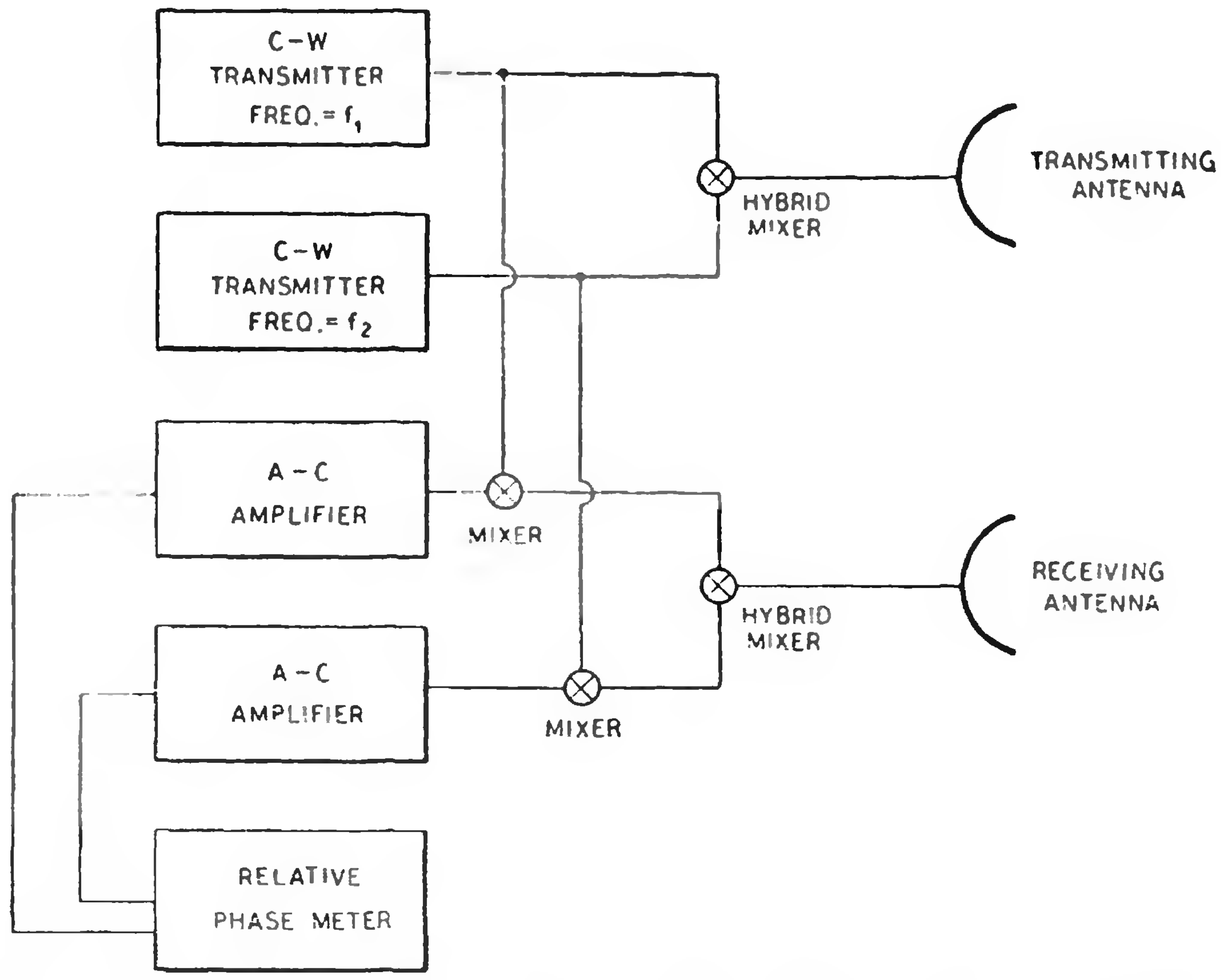
Calculated chamber pressure-time histories for several different grain configurations.



Typical solid propellant grain configuration.

From G. P. Sutton, "Rocket Propulsion Elements", Copyright Wiley & Sons, 1956, New York.

FIG. 10.17 RANGE-MEASURING (C-W) DOPPLER RADAR



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largely cyclostrophic winds until they travel north or south sufficiently to be affected by Coriolis force.

D

db
  (See Decibel)

dbm
  A signal strength measured as so many db below one milliwatt.

DEI
  (See Development Engineering Inspection)

DEW (Distant Early Warning)
  A line of radars for the detection of incoming targets at a considerable distance from the air defense system which must be alerted.

D Layer
  That portion of the ionosphere with a maxima of ionization in the region 35 to 40 miles. (See Atmosphere)

DME
  (See Distance Measuring Equipment)

DORAN
  A Doppler ranging system (elliptical) using phase comparison to establish missile range. (Very similar to DOVAP.)

DOVAP (Doppler Velocity And Position)
  A range instrumentation and safety system used to determine velocity and position by using electromagnetic radiation. An airborne frequency doubler is utilized and Doppler beat frequencies at several ground stations provide range data (by counting cycles which represent the sum of velocities for the propagation paths). Direct velocity measurement is provided.

DPO
  Development Planning Objective

Damage Agent
  An explosive carried within the warhead to be released against enemy target so as to cause the desired damage.

Damage Control (Naval)
  The means for controlling damage aboard ship incident to missile handling and launching and to enemy action.

Damage Volume of Missile
  Envelope of swept-out volume defined by range-limit of the destructive agent carried by the missile.

Damping
(1) The effect of friction or its equivalent in reducing oscillation of a system.
(2) In a system undergoing shock and vibration, the result of energy being absorbed by a component of the system and not returned to the system. This energy is usually dissipated as heat.

Damping, Aerodynamic
  (See Aerodynamic Damping)

Damping, Coulomb

(See Damping, Dry Friction)

Damping, Critical

(1) In an elastic mechanical system subjected to a periodic force, the amount of damping just sufficient to prevent vibration from occuring if the system is displaced and then released.

$$c_c = 2\sqrt{km} = 2m\omega_n$$

where k = spring constant
m = mass
ω_n = circular natural frequency

(2) The threshold value of damping which will just prevent oscillation in an electrical system subjected to a periodic forcing function.

(See Fig. 5.4, p. 520)

Damping Decrement

(See Logarithmic Decrement)

Damping, Dry Friction

The damping in a mechanical system resulting primarily from friction forces which are independent of velocity or displacement. The damping force is equal to the coefficient of friction times the normal force.

Damping Ratio (Viscous Damping Ratio $\frac{c}{c_c}$)

The ratio of the actual damping coefficient for an oscillating mechanical system to the coefficient for a critically damped system.

$$\frac{f_d}{f} = \sqrt{1 - \left(\frac{c}{c_c}\right)^2}$$

where f_d = damped natural frequency, fps
f = undamped natural frequency, fps
$\frac{c}{c_c}$ = damping ratio.

Damping, Structural (c)

Damping caused by structural impedance in an oscillating mechanical system. Equals $2(\frac{c}{c_c})$. (See Eq. 4.21, p. 183)

Damping, Viscous

The damping in a mechanical system in which the force varies in proportion to the velocity. The viscous-damping coefficient is equal to the ratio of the viscous-damping force to the velocity.

Data Acquisition

That phase of data handling associated with obtaining, measuring and/or recording the basic parameter(s) to be measured: e.g., telemetering transducers are part of the data acquisition system.

Data Handling System

Automatically operated equipment engineered to simplify the use and interpretation of the mass of data gathered by modern instrument installations. Also termed Data Reduction System.

Data Reduction

The process of converting recorded data into meaningful form, e.g., curves or tables.

Data Reduction System

(See Data Handling System)

Dead Band

In a servo system a specific range of values in which an incoming signal can be altered without also changing the outgoing response. Sometimes termed dead zone.

Dead Reckoning

The navigation process used to obtain the approximate position of a vehicle by integrating estimates of velocity, direction, wind, current, etc. over the period of time since the last established fix.

Dead Space

In a hydraulic transfer valve, the range of input currents around null (zero load flow) where the load flow of the valve remains essentially zero.

Dead Time

An interval following response to one signal or event during which a system is unable to respond to another.

Dead Zone

(See Dead Band)

Decay, Exponential

(See Exponential Decay)

Decca Navigation

(See Navigation, Hyperbolic)

Deception, Electronic

Electronic deception is the radiation or reradiation of electromagnetic energy in a manner intended to mislead the enemy in the interpretation of data received by his electronic equipment.

Deception, Imitative

Imitative deception is the transmission of messages in the enemy's communication channels with the intention of deceiving the enemy.

Deception, Manipulative

Manipulative deception is the manipulation of traffic in friendly communication channels with the intention of deceiving the enemy.

Deception Meaconing

(See Meaconing)

Deception, Radio

Radio deception is the employment of radio to deceive the enemy; it includes sending false dispatches, using deceptive headings, employing enemy call signals, etc.

Decibel (db)

A unit for expressing the magnitude of a change in sound or electrical power level. One "db" is approximately the amount that the power of a pure sine wave sound must be changed in order for the change to be just barely detectable by the average human ear. The bel is the fundamental division of a logarithmic scale expressing the ratio of two amounts of power, the number of bels denoting such a ratio being the logarithm to the base ten of this ratio. The decibel is one-tenth of a bel. For example, with P_1 and P_2 designating two amounts of power and n the number of decibels denoting their ratio

$$n = 10 \log_{10} \frac{P_1}{P_2}, \text{ decibels}$$

When the conditions are such that ratios of voltages or ratios of currents (or analogous quantities such as force or velocities, torques or angular velocities, pressures or volume currents) are the square roots of the corresponding power ratios, the number of decibels by which the corresponding powers differ is expressed by the following formulas:

$$n = 20 \log_{10} \frac{i_1}{i_2}, \text{ decibels}$$

$$n = 20 \log_{10} \frac{e_1}{e_2}, \text{ decibels}$$

where i_1/i_2 and e_1/e_2 are given current and voltage ratios respectively. A common reference level is zero "db" with one milliwatt into a 600 ohm load; and sometimes 10^{-16} watts/sq. cm. pressure. (See Fig. 6.2 and 6.3)

Deck Motion Predictor

A device to predict at given intervals and at a time prior to missile firing, ship's motion about its fore and aft and athwartship's axes in such a manner as to permit firing a missile at a desired condition of ship's attitude and motion.

Decoder

A device, usually in the airborne portion of the guidance system, which accepts only properly coded guidance and command signals. (Coding is used to avoid enemy and friendly jamming, increase traffic handling capacity and permit increased data transmission on one link).

Decoder, Digital-Analog

A device for converting information available in digital form into a form suitable for utilization by an analog device. (Encoders are used to convert analog to digital form.)

Decontamination

Removal of radioactive materials.

Decoy

A countermeasure device intended to divert a guided missile or other weapon from its proper target.

Decrement, Logarithmic

(See Logarithmic Decrement)

Deep Water Burst

An underwater nuclear burst in which the center of detonation is at a depth of at least 1000 ft.

Defensive Firepower

The capacity of a target to inflict damage on an attacker.

Defensive Missile

One which is used to thwart an enemy attack which is proceeding against friendly forces or resources. An offensive missile is used to destroy enemy forces or resources which could be employed at a later time.

Deflagration

(See Detonation)

Degenerative Feedback

(See Feedback, Inverse)

Degrees of Freedom

(1) The number of independent coordinates necessary for the unique determination of the position of every particle in a

dynamical system is the number of degrees of freedom. Each degree of freedom is represented by a coordinate which can vary with time independently of all the rest. Thus a single particle which may move anywhere in three-dimensional space has three degrees of freedom. A particle constrained to move on a surface has two degrees of freedom, etc..

(2) In the statement of the phase rule, one of that number of variable factors such as pressure, temperature or concentration which must be fixed to define completely the state of the system.

(3) The number of independent meshes, or the number of independent circuits that may be selected in a network.

Delay Line

In electronics, an artificial transmission line employing lumped constant elements to provide a predetermined time for a waveform to traverse a line. (Delay times of 1 μ are readily obtainable; long times are difficult because of the large number of sections required to provide sufficient delay and still give sufficiently high cut-off frequencies.)

Deluge System

A water washdown system installed on missile test stands or launch stands to permit inundation in case of fire or other accident,

Demodulation

The reverse of modulation. The process of extracting the audio or video frequency component from the modulated RF signal. Commonly called detection (e.g., the function of the second detector in a superheterodyne radio receiver).

Dependent Component

In reliability studies those components which interact significantly with the rest of the system.

Depleted Uranium

Uranium ore or slag having less than the natural content, namely, 0.7 percent, of the easily fissionable uranium-235.

Depot-level Maintenance

(See Maintenance, Depot)

Derating

A design technique of limiting the required functional performance of a part or component when it is subjected to a severe environment or required to operate for a long period with high reliability.

Derivative Action

Control operation in which the speed of a corrections is made according to how fast the system error is increasing (same as rate action).

Derivatives, Stability

Aerodynamic quantities expressing the variation of the forces and moments on aircraft owing to disturbance of steady motion. They form the experimental basis of the theory of stability, and from them the periods and damping factors of aircraft can be calculated. In the general case there are 18 translatory and 18 rotary derivatives.

Descent Path

Flight path leading from an orbit in space to the surface of a celestial body.

Design Load

(See Load, Design)

Design Objective

A non-contractural means of specifying certain desirable performance or operating characteristics. (Frequently used when a design feature is difficult to validate: e.g., very high reliability requirements, probability of survival of blast, etc.)

Design Temperature

A temperature which high speed aerodynamic surfaces must be designed to resist. It is based on the boundary layer temperature:

$$t = 0.84 \frac{V^2}{12{,}000} \text{ for laminar flow}$$

$$t = 0.90 \frac{V^2}{12{,}000} \text{ for turbulent flow}$$

where t is in °F and V is in fps.

Destructive Agent

Material contained in warheads such as explosives, corrosive chemicals, biological agents, etc., which damage or destroy the target.

Destructor

An explosive or other device for intentionally destroying a missile or aircraft, or a component thereof.

Detail Specification

(See Specification, Detail)

Detector, Impact

A device that generates a voltage upon impact with a surface. Generally used to fire a warhead.

Detector, Proximity

A sensing device that produces an electrical signal when passing near an object or prior to impact.

Detonation (Explosion)

An extremely rapid reaction, in which an oxidizer and a fuel combine with large evolution of heat. The release of warhead damage agents, usually by initiating a series of explosive elements arranged in a "chain". A high-order detonation, or "true detonation", proceeds with very high speed, generally several thousand feet per second. A low-order detonation is a partial, or relatively slow, explosion, generally caused by accidental or inadequate initiation. The term detonation is not to be confused with deflagration, which may consume the same explosive materials, but at a rate usually of the order of inches per second.

Detonator

A combination of a primer and another less-sensitive explosive charge. Electrical type is detonated by a current of approximately one half ampere. Typical material is tetryl in the form of a reconsolidated pellet.

Development

The application of known techniques and principles to produce a desired result from the discoveries of research. In the development stage a device is visualized and its performance is anticipated. Development is characterized by deliberate planning, by ingenuity, and by synthesis of knowledge in many fields. The result of development is the creation of plans or models for a new device, and the demonstration by test that the prototype of the device fulfills the objective of the development.

Development Engineering

Creation of a design, parts of which make use of new facts discovered by research.

Development Engineering Inspection (DEI)

A formally conducted inspection of a missile or system mockup in which development and using commands review the weapon to determine desirable changes. Requests for Alterations (RFA's) are prepared by the inspection board and eventually are acted upon by the contractor.

Deviation

A contractual change to a specification or work statement; a temporary change or departure from a particular requirement of a contract or other document and granted on equipment if it does not conform to the specification.

(See Waiver)

Deviation (of a Signal)

The frequency change from the center frequency governed by the amplitude of the modulating system. The modulating signal does not vary the amplitude of the carrier but does shift the frequency and power to different sidebands.

Dew

If air in contact with any surface is cooled at the surface to a temperature below its dew point, some of the water vapor present in the air will condense onto the cool surface as liquid water or dew. When temperatures are below freezing, hoarfrost forms instead.

Dew Point

The temperature at which the actual content of water vapor in the atmosphere is sufficient to saturate the air with water vapor. If the atmosphere contains much water vapor the dew point is higher that in the case of drier air, so that the dew point is an indication of the relative humidity of the atmosphere.

Diergolic (Non-hypergolic)

A property of liquid propellants (oxidizer and fuel) that do not react spontaneously when brought into contact but require an auxiliary ignition system to initiate combustion.

Diffuser

A duct of varying cross section designed to convert a high-speed gas flow into low-speed flow at an increased pressure. (See Fig. 10.15, p. 419)

Diffuser, Area Ratio of

The ratio of the outlet cross-sectional area of a ramjet diffuser to the inlet cross-sectional area.

Diffuser Buzz

In ramjet engines, an oscillatory motion with alternate swallowing and expelling of the normal shock system resulting in pressure variations throughout the diffuser. Buzz can only occur when the normal shock is expelled outside the cowl intake lip.

Diffuser Efficiency

(1) The ratio of the actual pressure increase realized by the diffuser to the theoretical pressure increase realized in an isentripic process.
(2) The ratio of the stagnation pressures after and before the diffuser.
(3) The ratio of actual change in enthalpy to the ideal change in enthalpy for passage from ambient to diffuser pressure.
(See Fig. 7.2.3, p. 284)

Diffuser, Kantrowitz-Donaldson

A type of supersonic diffuser, which first contracts to a throat and then expands. Under proper operating conditions a normal shock occurs near the throat at decreased gas stream velocity, thereby decreasing the shock - wave strength and the pressure losses which would occur if the normal shock had occurred at the lip of the diffuser.

Diffuser, Oswatitsch (Ferri or Spike)

A type of supersonic diffuser for ramjet, with an inner body projecting forward of the diffuser lip designed to permit pressures to be raised gradually through a series of conical shocks. The pressure recovery possible with this type of diffuser operating at high Mach numbers is considerably greater than could be obtained by a diffuser designed for single normal shock. (See Fig. 10.15, p. 419)

Diffuser, Perforated Inlet

An intake designed to reduce spillover of the approaching supersonic air by causing some of the air entering the diffuser to flow through the perforations due to the differential pressure. The effect is to move the shock wave closer to the diffuser intake. (See Fig. 10.15, p. 419)

Diffuser Spillover

That part of the approaching free air stream that does not enter the diffuser direct but is spilled over the lips.

Diffuser, Subsonic

The forward section of an air-breathing engine which reduces the Mach number of the supersonic stream to the low value required at the entrance to the combustion chamber.

Diffuser, Supersonic

The forward section of an air-breathing engine which is designed to reduce the supersonic airstream to practically a sonic stream.

Digital Computer

A computer in which quantities are represented in numerical (as distinct from analog) form and which generally is made to solve complex mathematical problems by iterative use of the fundamental processes of addition, subtraction, multiplication, and division.

Diode

A two-electrode device, having an anode and a cathode, which has marked unidirectional characteristics. (See Diode, Crystal; Diode, Junction)

Diode, Crystal

A diode consisting of a semiconducting material, such as a germanium or silicon, as one electrode, and a fine wire "whisker" resting on the semiconductor as the other electrode. Because of its low capacitance, the device finds considerable application as a rectifier or detector of microwave frequencies.

Diode, Junction

A semiconductor with good rectifying characteristics; generally less noisy than point contact types.

Dip (Magnetic Inclination)

The angle, in the plane of the magnetic meridian, that compass magnet is inclined to the horizontal.

Dipole

In nucleonics and electronics:

(1) A combination of two electrically or magnetically charged particles of opposite sign which are separated by a very small distance.
(2) Any system of charges, such as a circulating current, which has the following properties:
   (a) No forces act on it in a uniform field;

(b) A torque proportional to sin θ, where θ is the angle between the dipole axis and a uniform field, does act on it;
(c) It produces a potential which is proportional to the inverse square of the distance from it.

Dipole Antenna
(See Antenna, Dipole)

Direction
The angular measure, usually from true north, to a point of interest. At any point along a trajectory it is the inclination of the trajectory to the meridian of the point, measured clockwise from 000 degrees at true north through 360 degrees.

Directional Coupler
A device used to extract a small amount of RF power from one waveguide to another as means for measurement of transmitter frequency, spectrum of the transmitted pulse and receiver sensitivity. (Used in conjunction with a slotted guide or line.)

Directional Stability
(See Stability, Directional)

Disarm (Unarm)
The act of rendering the armament system incapable of operation by interrupting the explosive train.

Disassociation
An effect of a high speed missile upon the atmosphere it encounters, i.e., the breaking down into atomic form of the molecules of nitrogen and oxygen. At Mach numbers between about 10 and 14 this is the major change in molecular structure. Electronic excitation and ionization are minor portions of the process.

Discriminator
In electronics:
(1) A device wherein amplitude variations are derived in response to frequency or phase variations.
(2) A circuit used in connection with counters, having the property that only pulses falling between two limits of amplitude (one of which may be 0 or ∞) are recorded.
(3) A special type of detector used after amplification in the IF stage to establish whether the IF deviates from the correct value.

Dish, Radar
(See Radar, Dish)

Dispersion
The scatter of impact points of a group of missiles about a particular aiming point.

Dispersion Area (Guidance)
That area enclosing the intersections of a large number of missile trajectories with perpendicular plane just in front of the target; used to analyze the performance requirement of an armament system.

Displacement Gyroscope (Free Attitude)
(See Gyroscope, Displacement)

Distance Measuring Equipment (DME)
A generalized term pertaining to guidance, range instrumentation or safety systems designed to indicate the radial distance between two locations.

Distortion, Harmonic
In electronics, a nonlinear distortion characterized by the appearance in the output of harmonics other than the fundamental component when the input wave is sinusoidal. Harmonic distortion is sometimes called amplitude distortion.

Disturbed Orbit
(See Orbit, Disturbed)

Dither
A force of controlled amplitude and frequency applied to a servo-motored transfer valve, so that the valve is constantly in small amplitude motion and cannot stick at its null position. Also termed Buzz.

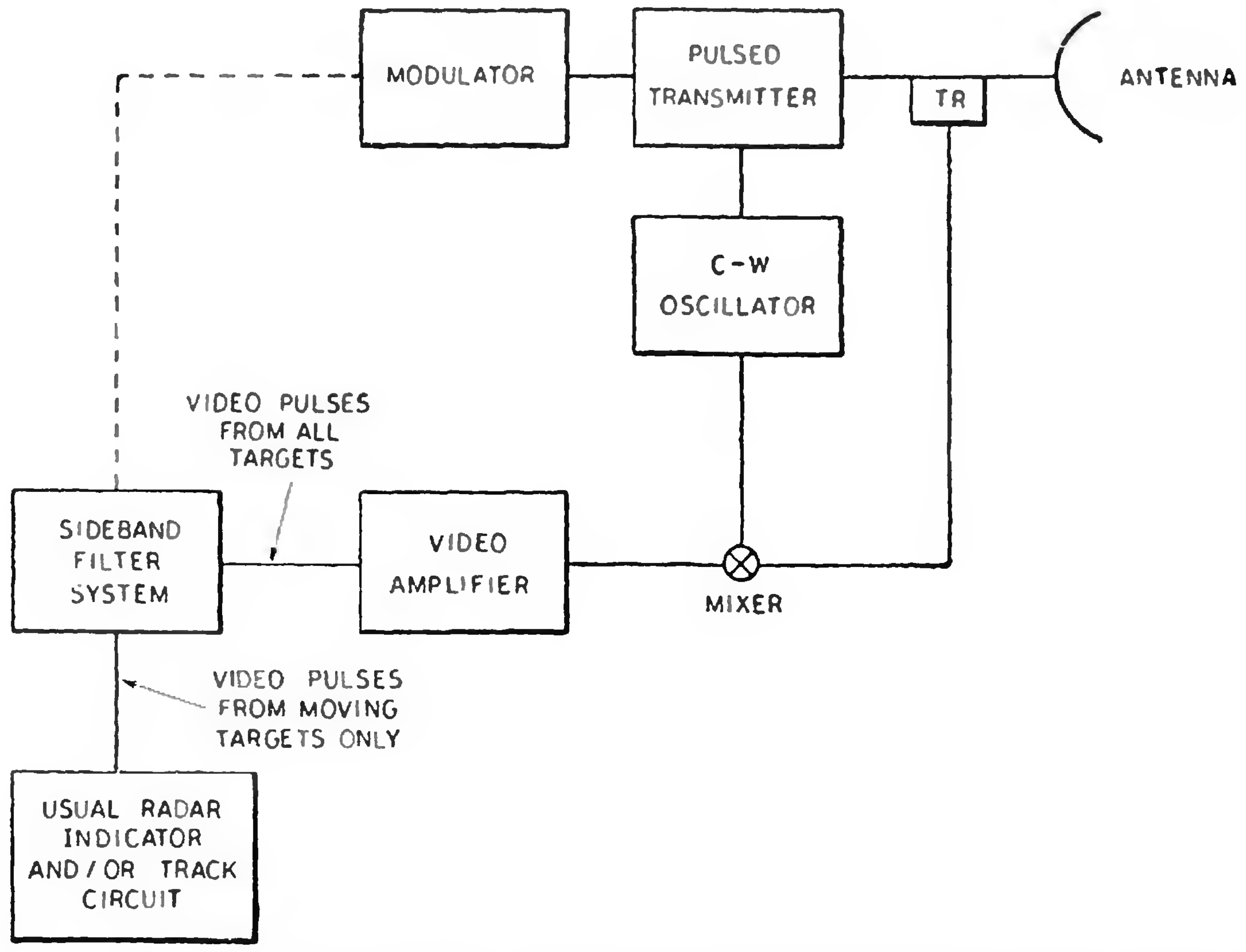
Doldrums
(See Front, Intertropical)

Doppler Effect
The apparent change in frequency of a sound or radio wave, reaching an observer of a radio receiver, caused by a relative speed and consequent change in distance or range, between the source and the observer or the receiver during the interval of reception.

Doppler Frequency
(See Doppler Shift)

Doppler Radar
Radar, either C-W or pulsed, which utilizes the Doppler Frequency shift of a reflected echo due to relative motion of target and radar. (For comparable maximum range performance, the peak power

FIG. 10.18 DOPPLER RADAR



of a pulsed radar is likely to be in the order of hundreds of kilowatts and that of a C-W Doppler radar in tens of watts. The average powers of these two radar systems, however, will be equal if they are designed to have the same maximum range capability. A Doppler system, unless gated, is capable of unambiguous tracking under the special condition that only one moving target exist within the antenna beam. This condition is no different than that encountered in a pulsed radar, in that some special feature of the target, usually its range, allows it to be selected from all others for tracking. In a Doppler system only two means of selection are available, namely, Doppler signal frequency and Doppler signal amplitude. The basis of selection is usually Doppler frequency and the mechanism is commonly a highly selective tunable filter such as is contained in commercial wave analyzers. Narrowing the filter bandwidth gives a greater amount of definition just as reducing the range gate duration in a pulse radar improves definition. (See Fig. 10.17, p. 424, 10.18 above, and 6.12, p. 245)

Doppler Shift

In radio technology, a Doppler phenomenon analogous to that occurring in sound propagation. The amount of the shift is doubled because of the two-way transmission (to the target and return). The comparison between the transmitted and received frequencies results in a difference, or beat frequency, sometimes termed the Doppler frequency, f_D. (See Fig. 6.12, p. 245)

Dose (Dosage)

The amount of nuclear radiation delivered to a specified area or volume, or to the whole human body.

Double Amplitude

(See Amplitude, Peak-to-Peak)

Double-Balanced Modulator

(See Ring Modulator)

Double-Base Powder

A propellant containing nitrocellulose and another principal explosive ingredient.

Double-Base Powder Propellant

(See Propellant, Double-Base Powder)

Double-Base Propellant

(See Propellant, Double-Base)

Double Sampling

Sampling inspection in which the inspection of the first sample leads to a decision to accept, to reject, or to take a second sample and the examination of a second sample, when required, always leads to a decision to accept or to reject.

Down-Time

The calendar time in which the system is not considered in condition to perform its required function.

Downwash

A wing-tail aerodynamic interference effect which affects the lifting efficiency of aft surfaces when these are either controlling or stabilizing the missile about its center of gravity. This effect will cause positive trim angles of attack to exist with wing control types even though the wing hub may be located on the overall missile center of gravity. The downwash produced by a given angle of attack increases as the aspect ratio is reduced.

Drag

The resistance of a missile to motion in a fluid. In a supersonic missile it is generally made up of three different types: (a) wave drag, (b) skin friction, and (c) drag due to normal force. The total of the wave drag— that is, drag forces due to pressures acting on the missile at zero angle of attack – and the skin friction is usually referred to as the zero-lift drag, whereas the component of normal force acting in the airstream direction (and existing solely due to the resultant normal force) is referred to as the lift-drag. The zero-lift drag is made up of total pressure drag of the body, wings, and tails as well as the pressure effect of any protuberances, plus the skin friction acting over the entire body surfaces. The wave drag of a missile usually constitutes approximately one-half of the total zero-lift drag of a typical supersonic missile, the rest being made up by skin friction.

Drag Due to Normal Force

(See Drag)

Drag-Weight Ratio

A useful aerodynamic ratio relating the total drag of the missile to the total weight.

Drift

(1) In a gyroscope, the displacement of the gimbals due to bearing friction, weight of lead wire, anisoelastic effects, mass unbalance, etc.

(2) In an amplifier (and other electronic devices) the departure of the characteristic output from the desired value; due to circuit unbalance, temperature, etc.

(3) In guidance, the gradual motion of the missile away from the desired trajectory; caused by misalignments, electrical biases, etc.

Drizzle, Atmospheric

An atmospheric condition wherein numerous very small liquid droplets whose diameter is less than 0.5 mm and whose rate of fall is usually less than 3 m per sec. Normally the drops seem to float downward.

Drone

A remotely controlled pilotless aircraft used as a target or to perform tasks hazardous to a human pilot: e.g., probe a nuclear cloud, target practice, etc.

Drone, Target

(See Target Drone)

Drop Test

(1) An environmental linear acceleration test used to establish capability of equipment to withstand handling or drops in service.

(2) A generic term categorizing tests in which the equipment is dropped in a tower, from a height, etc.

Dry Run

A "dummy" test usually complete in detail except for actual operation of the equipment. Used to develop crew skills and to assess readiness for a full scale test.

Dry Stand

A type of rocket launcher having a flame deflector which is not liquid cooled.

Ducted Solid Propellant Rocket

(See Rocket, Ducted Solid Propellant)

Dud

(1) A missile which fails to operate during preparation, launching, or flight.

(2) Armament which fails to operate.

Duplex

Capability of an equipment performing two independent functions simultaneously: e.g., simultaneous firing from several launchers. Contrast with Simplex. (See Simplex)

Duty Cycle

In electronics:

(1) The time interval consumed by a device on intermittent duty in starting, running, stopping, and idling.

(2) The ratio of this time interval to the total time of one operating cycle.
(3) The ratio of the pulse width to the interval between like portions of successive pulses.

Dynamic Behavior
A term which describes how a control system or an individual unit performs with respect to time.

Dynamic Pressure (Total Head)
The pressure that a moving fluid would attain if it were brought to rest by isentropic flow up a pressure gradient. For an incompressible fluid, the dynamic pressure is the sum of the local pressure and the kinetic energy per unit volume.

Dynamic Pressure (q)
The pressure exerted upon a body by a fluid which is brought to rest against it. (See Fig. 2.14, p. 245)

Dynamic Stability
(See Stability, Dynamic)

Dynatron
A four-electrode vacuum tube so designed that secondary emission of electrons from the plate causes the plate current to decrease as plate voltage is increased, giving a negative resistance characteristic. Used in oscillator circuits.

E

ECL
Equipment component list.

ECM
Electronic Countermeasures. (See Countermeasures)

ECP
Engineering change proposal.

EDPC
Electronic Data Processing Center.

EDPS
Electronic Data Processing System. Part of the Air Materiel Command network for logistics support.

E Layer
That part of the ionosphere with a maxima of ionization in the region 70 to 80 miles altitude.

Eput Counter (Events per unit time)
An electronic device for high speed counting.

EMA
(See Electronic Missile Acquisition)

EPS
(See Emergency Power Supply)

E & ST
Empoyment and Suitability Test. Corresponding missile test for an Operational Suitability Test for aircraft.

E-Vector
The vector representing the electric field of an electromagnetic wave. In free space it is perpendicular to the direction of propagation and to the H-Vector representing the associated magnetic field.

Early (Burst)
Warhead detonation during the period after the S and A but before target detection.

Early Bird
A missile which arrives at the intersection of the missile-target trajectories prior to the arrival of the target.

Early Warning System
Part of an air defense system usually comprising search radars, whose function is to detect and identify attacking enemy aircraft in time to permit effective use of the system's air defense weapons.

Earth, Non-Rotating
(See Non-Rotating Earth)

Earth Pendulum (84 min Pendulum; Schuler Pendulum)
A pendulum with a length equal to radius of the earth and a natural period of 84 minutes. It has the property of being insensitive to earth's rotation. Pendulous systems having the same period are similarly insensitive and are therefore much used in gyro reference systems.

$$T = 2\pi\sqrt{\frac{L}{g}} = 2\pi\sqrt{\frac{3963 \times 5280}{32 \times 3600}} = 84 \text{ min}$$

Earth's Rate

The apparent angular motion of a space-stabilized gyroscope caused by the earth turning on its axis (at 15° per hour). Gyro drift is measured as a fraction of earth's rate.

Echoing Area of Target, Effective

In radar technology, the area of an hypothetical target, normal to the incident beam, which re-radiates equally in all directions all the energy incident on it, and produces at the receiver a signal equal to that produced by the actual target. The value of A_e for an actual target depends on many factors, and can only be found empirically. For an average aircraft it is of the order of 1 to 10 square meters. (See Fig. 6.22, p. 256)

Effective Mechanomotive Force

(See Force, Effective)

Effective Sound Pressure

(See Sound [Acoustomotive] Pressure)

Effective Static Stability

(See Stability, Effective Static)

Einstein Equation

A fundamental equation expressing the equivalence of energy and mass.

$$E = mc^2$$

where m is the mass converted and c is the velocity of light. (One kilogram of uranium or plutonium must be fissioned to yield the energy equivalent of 20,000 tons of TNT, (which is 2×10^{13} cal = 8.4×10^{20} ergs = 2.3×10^7 kwh.)

Elasticity, Anomalous

Property of a material in which the stress-strain curve does not fit an easily derivable mathematical expression.

Elasticity, Bilinear

Property of a material in which the stress-strain curve has the general shape shown in Fig. 10.19, i.e., describable mathematically by two straight line functions.

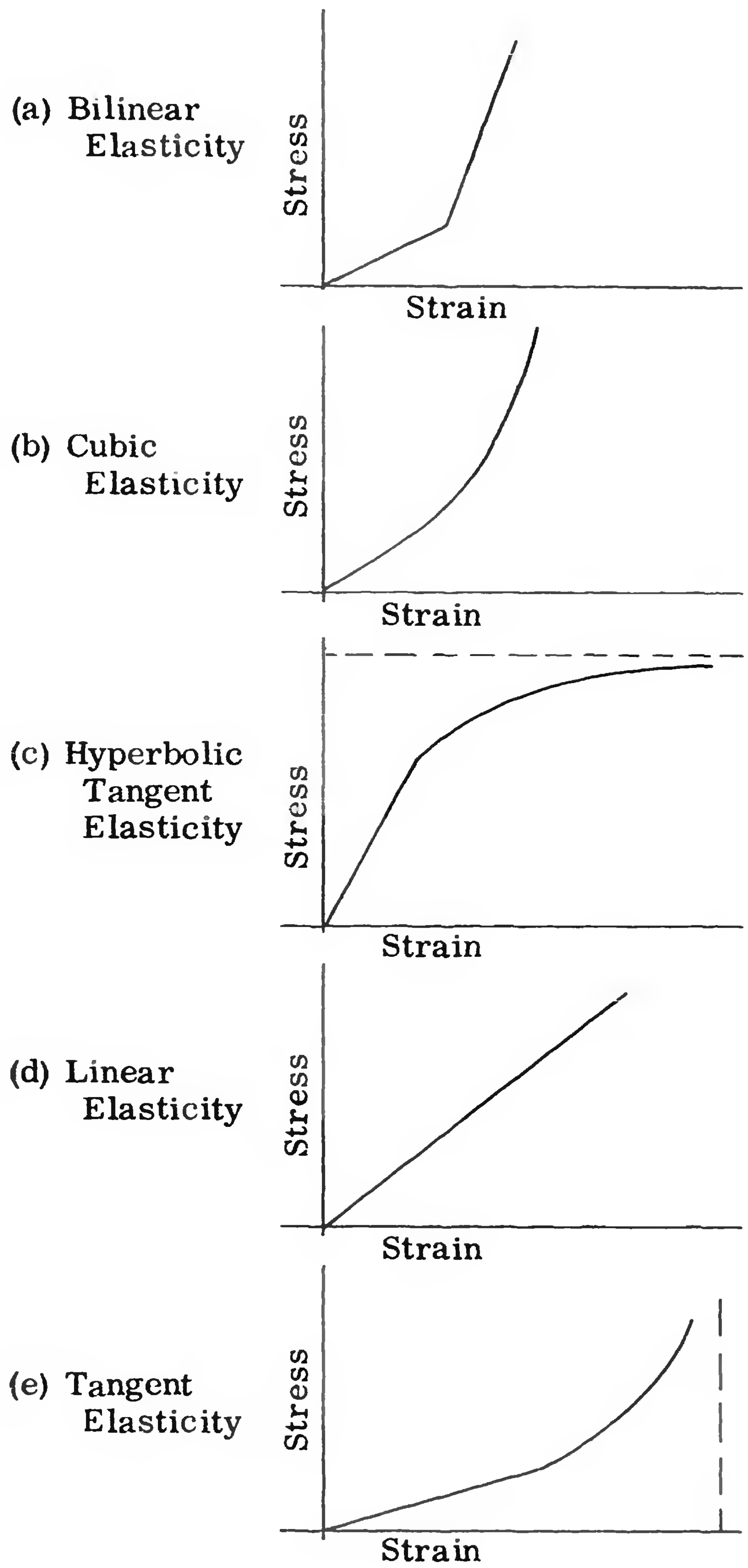
Elasticity, Cubic

Property of a material in which the stress-strain curve has the general shape shown in Fig. 10.19, i.e., describable mathematically by a cubic function.

Elasticity, Hyperbolic Tangent

Property of a material in which the stress-strain curve has the general shape shown in Fig. 10.19, i.e., describable mathematically by a hyperbolic tangent function.

FIG. 10.19 TYPICAL STRESS-STRAIN CURVES



Elasticity, Linear

Property of a material in which the stress-strain curve has the general shape shown in Fig. 10.19, i.e., describable by a straight line function.

Elasticity, Tangent

Property of a material in which the stress-strain curve has the general shape shown in Fig. 10.19, i.e., describable mathematically by a tangent function.

Elastic Limit

The least stress that will cause permanent set of a material.

Electrical Interference
(See Interference)

Electrical System
A system adapted for the transmission of electrical currents consisting of one or all of the electrical elements: electrical resistance, inductance and electrical capacitance which, added vectorially, constitute the electrical impedance.

Electroforming
The electrolytic deposition of metal upon a conducting mold, to make a desired metal object, such as precision tubing or medals. The mold is often of graphite-coated wax, so that it can be removed by melting.

Electromagnetic Radiation
Radiation made up of oscillating electric and magnetic fields and propagating with the speed of light. Includes gamma radiation, X-rays, ultraviolet light, visible light, infrared radiation, radar and radio waves.

Electron
A very small negatively charged particle. Electrons appear to be uniform in mass and charge and to be one of the basic units of which atoms are made. The negatively charged electrons surrounding an atomic nucleus form an atom. Each electron has 1/1840 the mass of a light hydrogen atom.

Electronic Countermeasures (ECM)
(See Countermeasures)

Electronic Deception
(See Deception, Electronic)

Electronic Missile Acquisition (EMA)
A measuring system for providing angular data (azimuth and elevation angle) by a phase comparison of RF signals received from a missile.

Electron-multiplier Phototube
A vacuum-type phototube that employs secondary emission to amplify the electron stream emitted from the illuminated photo-cathode. The electron stream impinges in turn on each of a series of reflecting electrodes called dynodes, at each of which secondary emission adds electrons to the stream. In one tube, an amplification of approximately 2,000,000 times is obtained with nine dynodes. Also termed photoelectric electron-multiplier tube and multiplier-phototube.

Electron Tube
Any completely evacuated or gas-filled tube used to control the flow of electrons in a circuit. Vacuum tubes, phototubes, mercury vapor rectifier tubes and cathode ray tubes are all electron tubes.

Element, of a Physical System
An element or circuit parameter in an electrical system defines a distinct activity in its part of the circuit. In the same way, an element in a mechanical rectilineal, mechanical rotational or acoustical system defines a distinct activity in its part of the system. The elements in an electrical circuit are electrical resistance, inductance and electrical capacitance. The elements in a mechanical rectilineal system are mechanical rectilineal resistance, mass and compliance. The elements in a mechanical rotational system are mechanical rotational resistance, moment of inertia, and rotational compliance. The elements in an acoustical system are acoustical resistance, inertance and acoustical capacitance.

Elevation Quadrant
A measure of launcher elevation position. The measurement is made with a gunner's quadrant.

Elevon Control
(See Tailless (Elevon) Control)

Elsse Cotar (ELectronic Sky Screen Equipment)
A passive range instrumentation system using on the ground the Sky Screen System to receive transmitted data from any airborne transponder which may be used for other purposes: e.g., FM/FM telemetering transmits at a satisfactory frequency for this system.

Emergency Power Supply (EPS)
The emergency power supply is a primary battery that supplies electrical power for certain range safety components during missile flight.

Encoder (Analog-Digital)
A device for converting information available in analog computer form into a form suitable for understanding by a digital computer. (Decoders are used to convert digital to analog form.)

End Burner
(See Propellant, Restricted)

End Burning Grain
(See Restricted Burning Grain; Propellant, Restricted)

End Instrument
An instrument for measuring a quantity within an operating missile for transmission by telemetering; a transducer or pickup.

End Item
A final combination of end products, component parts, and/or materials that is ready for its intended use: e.g., a missile, a mobile guidance unit, a launcher.

End Organ
(See Telemetering Pickup; Organ, End)

Endothermic
A thermodynamic term descriptive of an absorption of heat or other energy.

End Product
Any material, part, sub-assembly, or assembly in its final completed state, as governed by specifications, drawing, provisions of contract or other requirements.

End Product Drawing
A drawing showing an end product. An end product drawing, covering the detail of an individual part, should include all dimensions, tolerances, notes and other data necessary to describe fully the size, shape, and other characteristics of the part as it appears in its completed state, but should not include references to intermediate steps in the production process, such as roughing operations with dimensions and limits pertaining thereto, or to specific manufacturing methods.

Endurance Limit
A limiting stress, below which metal will withstand without fracture an indefinitely large number of cycles of stress. If the term is used without qualification, the cycles of stress are usually such as to produce complete reversal of flexural stress. Above this limit failure occurs by the generation and growth of cracks until fracture results in the remaining section.
The effect of repeated reversal of stresses is to cold work the steel and the results produced are the same. From tests that have been made the endurance limit for steel appears to be obtained at 10^7 cycles and is approximately 1/2 the tensile strength. In plotting the results of these tests the load per square inch and the number of cycles are used as co-ordinates and are called S-N curves. In actual practice, allowances should be made for stress raisers such as notches, unequal stress applications, etc., and design varied accordingly. (See S-N Curves)

Engine, Rocket
(See Rocket Engine)

Engine, By-Pass
(See By-Pass Engine)

Environment
The aggregate of all the conditions and influences which affect the operation of equipments and components, e.g., physical location and operating characteristics of surrounding equipments and/or components; temperatures, humidity and contaminants of surrounding air; operational procedures; acceleration, shock and vibration; radiation; method of utilization, etc.

Environmental Engineering
That phase of engineering devoted to the study of cause and effect of the several environments in which equipment must live. Particularly for missiles this includes:

vibration	fungus
shock and impact	corrosion
temperature	pressure
climatology	

Environmental Protection
Unique steps taken to protect equipment from any or all of the following environments:
- shock
- vibration
- temperature
- corrosion
- abrasion (sand, dirt, dust, snow, hail, ice)
- moisture (humidity, snow, ice, hail, rain)

pressure
lightning
wind
sunshine
noise
fungus

Environmental Testing, Production

(See Production Environmental Testing)

Environment, Derived

A classification comprising natural uncontrolled environments:

temperature	lightning
humidity	sand
rain	dust
snow	dirt
ice	fungus
sleet	pressure
hail	salt spray
fog	static electricity
wind and gusts	

Environment, Induced

A classification comprising environments caused by the operation, location and/or previous environmental state of a missile:

vibration	erosion (in flight)
shock	electromagnetic effects
aerodynamic heating	force

Environment, Production-to-Target

The physical conditions existing at each step described in the production-to-target sequence; they are given in terms of temperature range, pressure, humidity, shock, vibration, acceleration, etc., with the time duration of each condition usually included.

Equilibrium Pressure

In a solid propellant rocket, the internal gas pressure which provides a rate of gas discharge through the nozzle equal to the rate of gas generation. (It depends upon rocket geometry, the burning rate of the propellant, and the initial temperature of the grain. The relationship between pressure and hence, thrust, and initial grain temperature is approximately linear. The impulse does not change appreciably over the usual temperature ranges, therefore, the change in thrust is accompanied by an inverse change in duration.)

Equipment

A combination of parts, assemblies or subassemblies capable of functional operation by itself (except the primary power supply as specified): e.g., an antenna, antenna tuner, radio transmitter and transmitter modulator, radio altimeter, turbo-pump, fuze, etc.

Equipment Component

A group of parts, subassemblies or assemblies combined in a separate housing and used as an element of an equipment: e.g., antenna tuner, radio transmitter, or transmitter modulator if each is in separate housing.

Equipment Component List (ECL)

A publication that prescribes the components of individual kits and organizational sets of equipment required for the performance of specific duties, functions, or support of end items of equipment.

Equipment (Hardware) Specification

A government specification which spells out in some detail the requirements for equipment. An extreme example is a set of working drawings; a minimum example is a set of schematic drawings.

Equivalence Ratio

The ratio of the stoichiometric air-to-fuel ratio to the experimental air-to-fuel ratio in an air-breathing engine.

Equivalent b.h.p.

The brake horse-power equivalent to a jet engine's thrust.

Erasing Head

A device for obliterating any previous recordings on a tape or wire recorder. It may be used for preconditioning magnetic media for recording purposes.

Erector

A system for raising or lowering the complete missile, or it's stages, from the horizontal to the vertical position.

Erosion

In a solid rocket, deformation of propellant due to heat, radiation, and gas velocity leading to erosive burning.

Error Signal

(1) In servomechanism, the signal, frequently a voltage, applied to the control circuit that indicates the

misalignment between the controlling and the controlled members.

(2) In tracking systems, a voltage, depending upon the signal received from the target, whose sign and magnitude depends on the angle between the target and the center of the scanning beam.

Escape Energy

The energy per unit mass which must be imparted to a missile to give it the escape velocity. (See Fig. 8.4, p. 314)

Escape Maneuver

(See Maneuver, Escape)

Escape Velocity

(See Velocity, Escape)

Exosphere

The outermost layer of the atmosphere in which the air particles travel in elliptical orbits with infrequent collisions. Approximately 1/3000 of the earth's atmosphere in terms of mass.

Exothermic

A thermodynamic term descriptive of an evolution of heat or other energy.

Exotic Fuels

(See Fuels, Exotic)

Expansion Ratio

In rocketry the ratio of nozzle exit area to the nozzle throat area. Always greater than unity.

Expansion Wave

A phenomenon of supersonic aerodynamics which occurs whenever air flows around a corner; that is, when the air tends to turn away from the air in the adjacent stream layer.

Explosive Chain

(See Explosive Train)

Explosive Train (Explosive Chain)

In missile armament, a series of explosive elements including primer, detonator, and booster, arranged to permit warhead explosion to be initiated from relatively weak fuze signals.

Exponential Decay

A characteristic reduction in amplitude, quantity, etc. which occurs frequently in nature. It is the decrease in the amount of a particular substance present according to the equation $A = A_0 e - \lambda^t$, where A and A_0 are the quantities present at times t and zero, respectively, and λ is a constant characteristic of the substance involved in the process.

Extra-planetary Space

(See Space, Extra-planetary)

F

FMB (Fleet Ballistic Missile)

An intermediate range ship-launched ballistic missile.

FCS

Federal Catalog System.

F Layer (F_1 and F_2)

That part of the ionosphere with a maxima of ionization. For the F_1 layer in the region 135 to 145 miles altitude and for the F_2 layer in the region 190 to 230 miles altitude. (See Fig. 10.5, p. 400)

F_2 Layer

The single ionized layer normally existing in the F region in the night hemisphere, and the higher of the two layers normally existing in the F region in the day hemisphere. (See Fig. 10.5, p. 400)

FM

(See Modulation, Frequency)

FM/FM Telemetering

(See Telemetering, FM/FM)

FSE

(See Field Support Equipment)

FSN

Federal Stock Number.

Facility, Research and Development

That part of an establishment which may include land, structures, equipment, or combinations thereof, used operationally in the pursuit of research, development, or tests and evaluations incidental thereto, and which physically occupies a single geographical location, e.g., wind tunnels, test stands, ballistic laboratories, climatic laboratories, etc.

Facility, Supporting

Any land, structure, apparatus, utility or combination thereof that contributes primarily to the support and/or operation of a research and development establishment, a test or evaluation facility, an operational base, or other primary facility but which, in itself, is not used operationally in the pursuit of research, development, tests, evaluations, etc.: e.g., housing and administrative buildings,

firehouses, roads, security installations, or distributive systems for water, fuel, electricity, air, steam, etc.

Factor of Safety

A design criterion, usually the ratio of the load that would cause failure of a member or structure, to the load that is imposed upon it in service. It may also be used to represent the ratio of breaking to service value of speed, deflection, voltage, temperature, or other stress-producing factor against possible increase in which the factor of safety is provided as a safeguard. (See Fig. 4.50)

Factor of Utilization

A design parameter, the ratio of the allowable stress to the ultimate strength. For cases in which stress is proportional to load, the factor of utilization is the reciprocal of the factor of safety.

Failure

Any physical phenomenon, no matter how small, which prevents the missile from achieving its objective.

Failure, Component-Compensating

A malfunction of one component of a system which nullifies the effect of failure of another component.

Failure, Component-Dependent

A malfunction of a component which is the direct result of the failure of another component.

Failure, Component-Independent

A malfunction of a component which does not affect the probability of vital failure of another component.

Failure, Component-Partial

A malfunction of a component which reduces the normal accuracy of the missile rather than causes a direct and complete failure of the missile.

Failure Modes

A classification system for failures of a missile system:

Chance - Random; encountered in unusually severe environments, unpredictable and unavoidable conditions during the operating period. Described by chance failure distribution. A statistical failure.

Wearout - Occurs due to wearing away of material or by using up a potential until the component reaches a condition where it can no longer operate according to specifications. Described by normal or Gaussian distribution, or better, by the binomial distribution.

Initial - Component is defective at time it is required to operate. Result of design errors, manufacturing errors, storage, assembly, handling, transportation, etc. Described by simple probability.

Failure Probability

One means of calculating the probability of failure of a component, based on the operations of the component and the possibility of a reduced margin of safety.

$$P_f = \frac{P_o P_i + (1 - P_o) P_s}{1 - P_o + P_o P_i}$$

P_f = probability of occurrence of a component failure under specified conditions.

P_o = probability of occurrence of a manufacturing error that will cause failure.

P_i = probability of occurrence of an inspection missing a manufacturing error.

P_s = probability of occurrence of a strength-stress scatterband overlap.

Fairing

An auxiliary member or structure of a missile whose primary function is to reduce the aerodynamic drag or to protect the part against aerodynamic forces. Usually it acts to shape outside surfaces in conformance with aerodynamic streamlines.

Fall-back

That portion of the material carried into the air by a nuclear explosion which ultimately drops back into the crater formed by an underground or surface burst, or into the water in the immediate vicinity of the site of the burst in the case of a water shot.

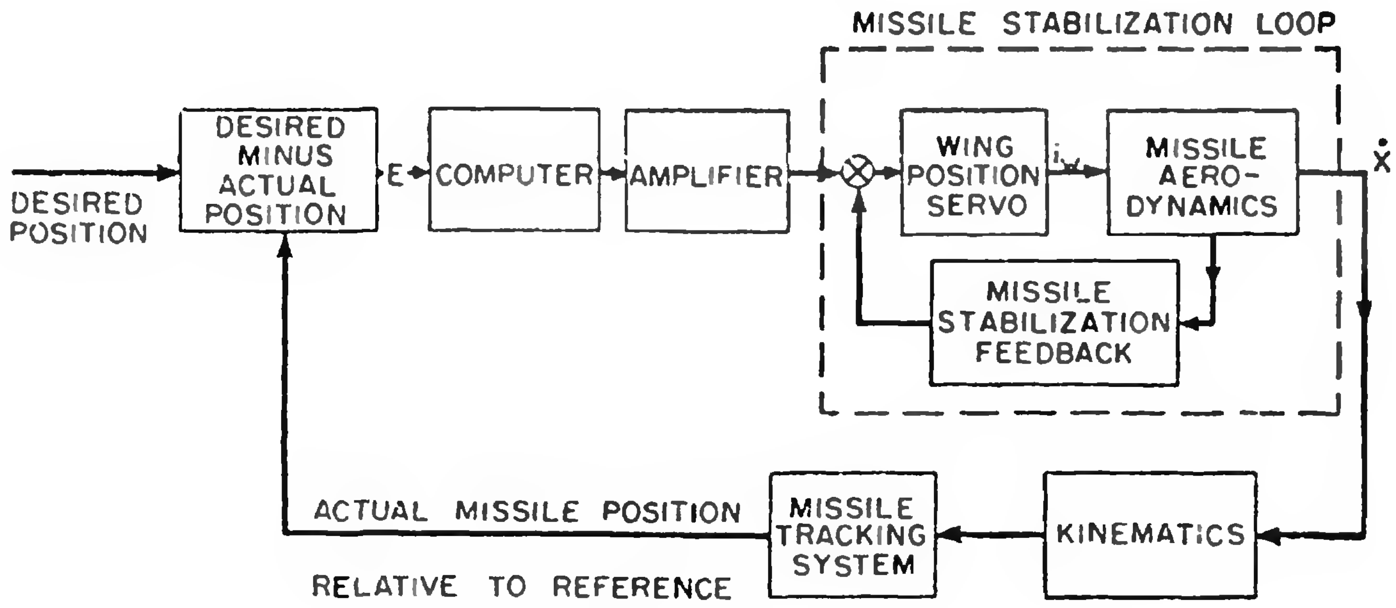
Fall-out

A deposit of radioactive material created by a nuclear explosion that has settled out of the air or from contaminated water.

Fall-wind

A wind blowing down a mountainside; or any wind having a strong downward

FIG. 10.20 MISSILE POSITIONING SERVO SYSTEM EMPLOYING WING POSITION CONTROL



component. Fall-winds include the Foehn, mistral, bora, williwaw, etc.

Fastax Camera

A high-speed motion picture camera used for observation of missiles at launch and for studying vibration phenomena in the laboratory. Frame speeds approach 7500 per sec. Accuracy between frames is measurable to about ± 1/4%.

Fathometer

A sonar device for measuring the depth of water beneath a ship.

Fatigue

The phenomenon of the progressive fracture of a metal by means of a crack which develops and spreads under repeated cycles of stress. (See Endurance Limit)

Feed System

(See Pressure Feed System)

Feedback

Part of a closed loop system which brings back information about the condition under control for comparison to the target value.

Feedback Filter, Inverse

(See Filter, Inverse Feedback)

Feedback, Inductive

(See Inductive Feedback)

Feedback, Inverse

A vacuum-tube circuit arrangement in which a voltage is fed back from the plate circuit to the grid circuit; used in radio-frequency circuits to improve the stability, and in audio-frequency circuits to reduce distortion and thus permit greater undistorted power output. Also termed degeneration, negative feedback, and stabilized feedback.

Feedback, Negative

Feedback which decreases amplification, being 180° out of phase with the input signal.

Feedback, Position

A type of feedback in control systems in which position of the controlled device is used as the reference: e.g., position of a wing, swivelled engine, radar dish, etc. (See Fig. 10.20)

Feedback, Positive

Feedback which increases amplification, being in phase with the original signal. (Contrast with Negative Feedback.)

Feedback Signal

In a control system, a signal responsive to the controlled variable. This signal is returned to the input of the system and compared with the reference signal to obtain an actuating signal which then returns the controlled variable to the desired value. (See Fig. 10.20)

Feint Attack

A simulated attack intended to draw enemy fire.

Ferri Diffuser

(See Diffuser, Oswatitsch)

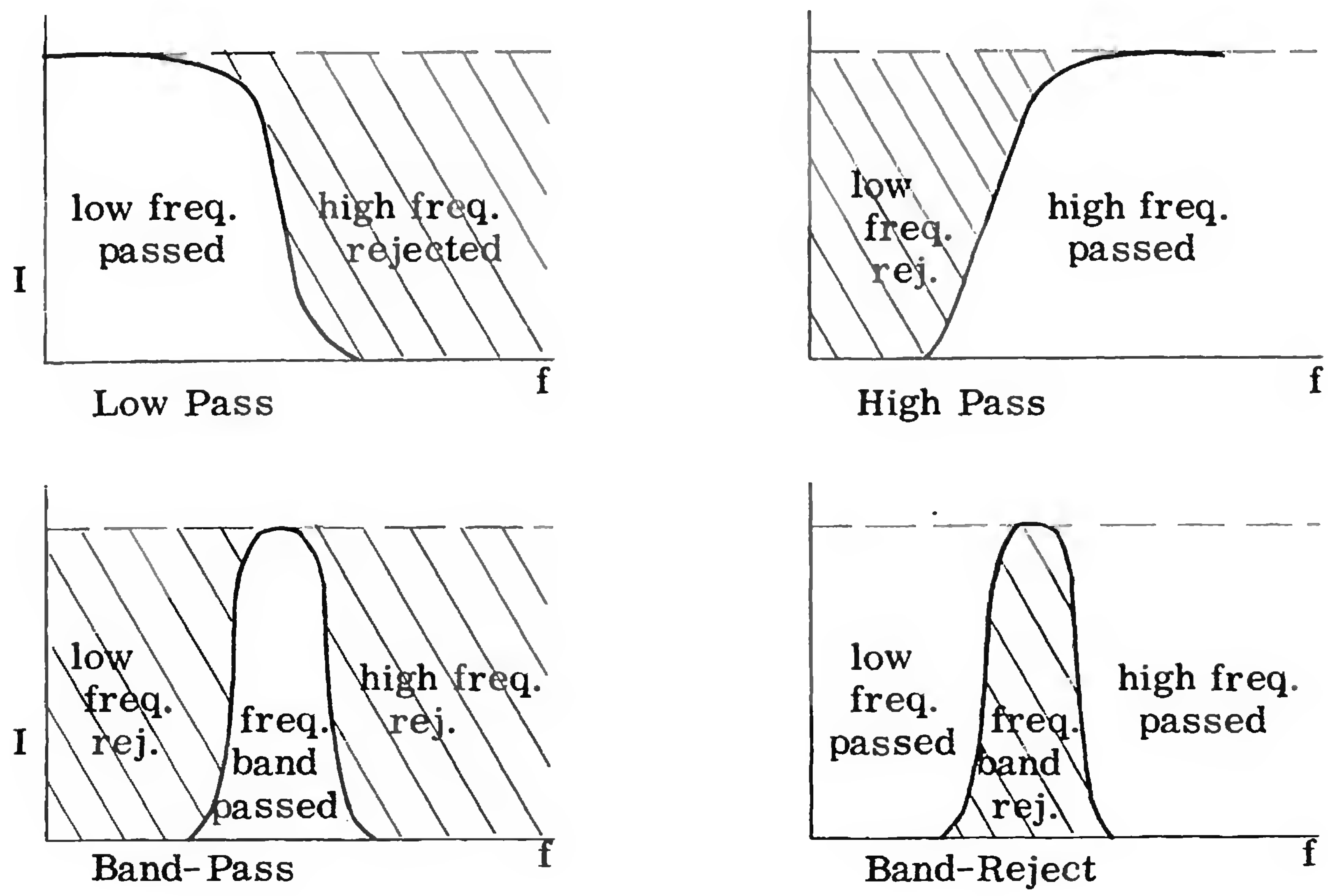
Fiducial Line

An accurately located and known reference line used for alignment of the airframe or guidance system. Frequently a line to which gyroscope axes are referenced.

Figures of Merit

For control systems, the gain margin, G, and phase margin β. Desired values are: G from 0.5 to 0.8 and β from 35 to 45 degrees.

FIG. 10.21 CHARACTERISTIC CURVES FOR FILTERS



Filter

A network employing lumped constant elements, used to select or reject signals in predetermined frequency ranges.

Filter, Active

A filter used for smoothing data. The time delay and/or phase lag introduced by such a low pass filter is cancelled by use of an identical "reciprocal" filter in the feedback circuit of the associated amplifier.

Field Support Equipment (FSE)

That portion of the unit mission equipment for T/0 units which permits their operations from a "bare strip".

Filter, Band-Elimination

(See Band-Elimination Filter)

Filter, Band-Pass

A network (electrical, mechanical or acoustical) which passes a band of frequencies between two particular frequencies. The geometrical mean is equal to the geometrical midfrequency of the pass band. (See Fig. 10.21)

Filter, Band-Rejection

A network (electrical, mechanical or acoustical) which rejects a band of frequencies between two particular frequencies. The geometrical mean is equal to the geometrical midfrequency of the reject band. (See Fig. 10.21)

Filter, Crystal

(See Crystal Filter)

Filter, High-Pass

In electronics, a wave filter having a single transmission band extending from some critical or cutoff frequency, not zero, up to infinite frequency. The value of the components may be selected as follows:

$$L = \frac{R}{4\pi f_c} \text{ and } C = \frac{1}{4\pi f_c R}$$

The cutoff frequency is:

$$f_c = \frac{1}{4\pi\sqrt{LC}}$$

L = inductance, henrys
C = capacitance, farads
R = load or terminating resistance, ohms (R is approximately the same value as the input or source resistor)

(See Fig. 10.21)

Filter, Inverse Feedback

A resonance bridge circuit used at the output of a high selectivity amplifier, such as an oscillator or wave analyzer. Impedance is adjusted so that the feedback output is zero for the resonant frequency, but increases rapidly as frequency departs from this value.

Filter, Low-Pass

In electronics, a wave filter having a single transmission band extending from zero frequency up to some critical or cutoff frequency, not infinite. The value

of the components may be selected as follows:

$$L = \frac{R}{\pi f_c} \text{ and } C = \frac{1}{\pi f_c R}$$

The cutoff frequency is:

$$f_c = \frac{1}{\pi\sqrt{LC}}$$

(See Fig. 10.21)

Filter, Mechanical

(See Mechanical Filter)

Filter, Notching

(See Notching Filter)

Filter, Octave

A band-pass filter which permits the passage of a range of frequencies from a lower limit to twice this value.

Filter, Structural

(See Structural Filter)

Fineness Ratio

In aerodynamics, the ratio of the length to the maximum diameter of a streamlined body. (See Slenderness Ratio)

Fire

To launch a missile.

Fireball

The luminous sphere which begins to form a few millionths of a second after a burst of an atomic bomb.

Fire Control

(1) A means of controlling fire power of a gun. A fire control system usually consists of a gun director, a computer and the gun on its trainable and elevatable mount. The gun director tracks the target. The computer establishes predicted future position of the target. The gun is directed according to the output of the computer.

(2) The term is sometimes applied to missile guidance when exercised outside the missile.

Firing Key

A device, either electrical or mechanical, which when actuated will initiate an action to launch the missile.

Firing Tables

For ballistic missiles, precomputed trajectories for given launch points and targets.

Fission, Nuclear

The division of a heavy nucleus into two approximately equal parts. For the heaviest nuclei the reaction is highly exothermic, the release of energy being about 170 Mev per fission. A well-known example is the fission of the compound nucleus formed when U^{235} captures a slow neutron. Other examples are the fissions of U^{233} and Pu^{239} by the capture of slow neutrons. The approximate equality of the fission fragments distinguishes fission from such process as spallation, in which relatively small fragments are ejected, leaving only one large residual nucleus. Fission has been induced by neutrons, charged particles, and photons. When induced by photons, it is called photofission. Spontaneous fission is fission that occurs without particles or photons entering the nucleus from the outside. For this rare mode of radioactive decay which occurs only in the heaviest elements, the half-lives for decay are, without exception, very long. Ternary fission is the splitting of a nucleus into three nuclear fragments; there is disagreement as to whether this term should be used for the often-observed type of fission in which a small charged nuclear fragment (such as a proton, alpha particle, tritium, or Li^8 nucleus) is emitted during the process of splitting into two massive fragments, or whether it should be reserved for splitting into three massive fragments, a process that has not been observed conclusively.

Fission Products

Elements and/or particles created by nuclear fission. In addition to uranium and plutonium, these may consist of more than 40 different radioactive elements: barium, iodine, cerium, arsenic, silver, tin, cadmium, and others.

Fission, Ternary

(See Fission, Nuclear)

Fittings

Structural elements used to join mechanically two or more parts, are usually designed for two loading conditions: limit load and ultimate load.

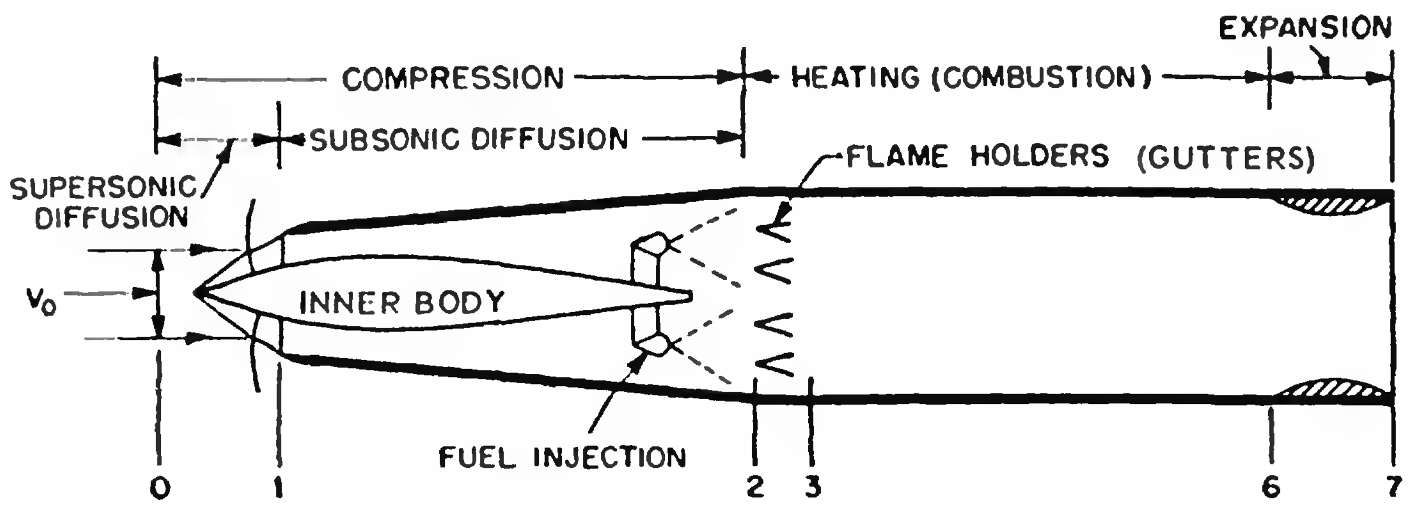
Fixed Equipment

(See Installed Equipment)

Fixed Error

A term used in precise alignments,

FIG. 10.48 SCHEMATIC ARRANGEMENT OF A SUPERSONIC RAMJET ENGINE



the offset between a preset position and the observed median value.

Flame Attenuation

A phenomenon occurring when microwave energy is directed through the exhaust gases from rocket or ramjet engines. The attenuation varies with the microwave frequency, the direction and power of the beam, the characteristics of the exhaust flow, the propellant, combustion efficiency, and altitude.

Flame Bucket

In liquid rocket engine test stands, the structure used to deflect the engine exhaust gases (often water-cooled).

Flame Deflector

A device for deflecting the exhaust flame of a rocket motor away from structural areas it might damage.

Flame Holder

A device inserted in the combustor of an air-breathing engine designed to stabilize a flame. (See Fig. 10.48)

Flame Out

(See Acceleration Blowout)

Flexure

The relative motion which occurs between structural parts of a missile, aircraft or ship. Flexure adversely affects the use of such a structure as a reference for direction sensitive devices.

Flight

The smallest Air Force organization possessing both launch and guidance capability.

Flight Control System

(See Control System, Flight)

Flight Path - (Trajectory)

The path of the center of gravity of a missile with reference to the earth.

Flight Table

A rate, roll, and/or tilt table used for gyroscope testing. It is used to check gyro position and/or rate outputs.

Flotation (Gyro Wheel)

In hermetically sealed integrating gyroscopes, a means of relieving the gimbal bearing load by floating the enclosed wheel assembly in a liquid. For a single axis gyroscope this liquid may be used for damping by controlling the viscosity.

Flow, Laminar

In aerodynamics, a particular type of streamline flow in which fluid in thin parallel layers tends to maintain uniform velocity. The term usually is applied to the flow of a viscous fluid near solid boundaries, when the flow is not turbulent.

Flow, Streamline

In a fluid flow, the path of particles originating at a common point. Except very near a body and in its wake a flow streamline does not change direction with time.

Flow, Turbulent

Any part of a fluid flow in which the velocity at a given point varies more or less rapidly in magnitude and direction with time.

Flutter (in aerodynamics)

An oscillation of definite period set up in any part of an aerodynamically active component by a momentary disturbance and maintained in a steady airstream by a combination of the aerodynamic, inertial and elastic characteristics of the member itself.

Flutter (in communication practice)

(1) Distortion due to variations in loss resulting from the simultaneous trans-

mission of a signal at another frequency.

(2) A similar effect due to phase distortion.

(3) In recording and reproducing the deviations in reproduced sounds from their original frequencies, which result in general from irregular motion during recording, duplication or reproduction.

The colloquial term wow is defined in the same way, but is commonly applied to relatively slow variations (for example, one to five or six repetitions per second) which are recognized aurally as pitch-fluctuations, in contradistinction to the roughening of tones, which is the most noticeable effect of rapid fluctuations. A constant difference in pitch such as results from a difference in the average speeds during recording and reproduction is not included in the meanings of the terms wow, flutter, and drift. By an extension of their meanings, the terms flutter and wow are used to designate variations in speed itself or variations in recorded wavelengths. Although most recorded sound comprises multitudes of tones, it is convenient to refer to flutter as variations in frequency, assuming the recorded sound to have been a single, steady tone.

Flutter Speed

The speed for constant amplitude motion.

Foehn Wind

On the lee side of mountains, air flowing downhill, dry adiabatically with attendant heating.

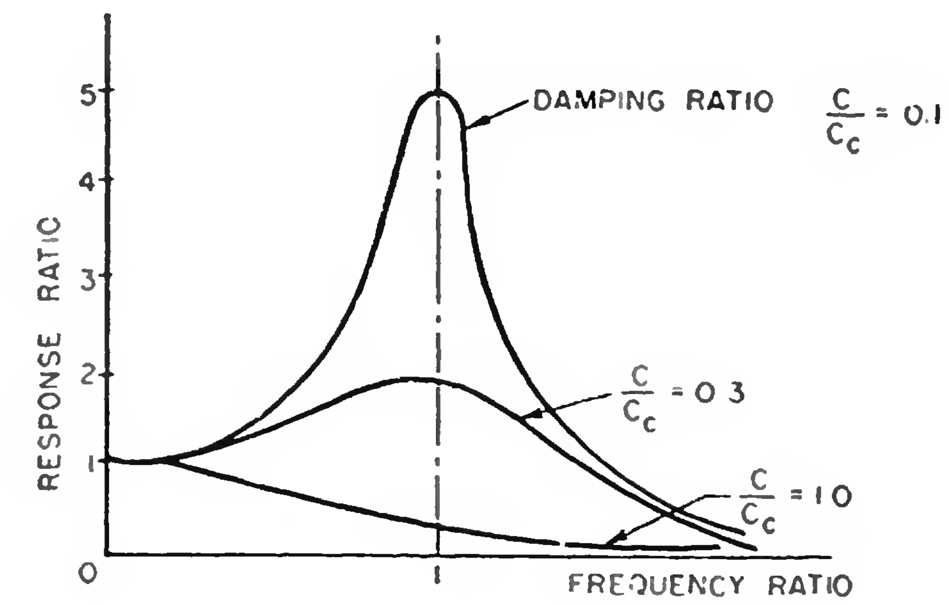
Fog, Radiation

A fog that develops in nocturnally-cooled air in contact with a cool surface. Radiation fog forms over land and not over water because water surfaces do not appreciably change their temperature during hours of darkness.

Fog, Upslope

A fog caused by dynamic cooling in air flowing uphill. Upslope fog will form only in air that is convectively stable; never in air that is unstable, because instability permits the formation of cumulus clouds and vertical currents.

FIG. 10.22 RESPONSE TO HARMONIC FORCING FUNCTION



FREQUENCY RATIO = $\frac{\text{FORCING FREQUENCY}}{\text{NATURAL FREQUENCY}}$

RESPONSE RATIO = $\frac{\text{DYNAMIC RESPONSE}}{\text{STATIC RESPONSE}}$

DAMPING RATIO = $\frac{\text{ACTUAL DAMPING}}{\text{CRITICAL DAMPING}}$

Follow-Up System

A colloquialism for servomechanism.

Force, Effective (Effective Mechanomotive Force)

In calculating loads on a structure imposed by complex forces the effective force is the root mean square of the instantaneous forces over a complete cycle. The unit is the dyne.

Forcing Function

A description of the characteristics and identity of a source of excitation. The function may be linear, non-linear, harmonic, random. The response is a function of the input, the damping and the inertial characteristics of the forced member. (See Fig. 10.22)

Foreign Intelligence

Information gathered by one nation in an effort to evaluate another nation's political and military capabilities and intentions.

Form Factor

A factor used in establishing a figure of merit or other criterion for packaging of electronic components and elements. It is used to give an indication of packaging efficiency or space utilization.

Fragmenting Warhead

(See Warhead, Fragmenting)

Free Molecular Flow

Physical property of a gas in which the mean free path of a molecule is large

compared to its size. Usually arbitrarily limited to the point where the path is 10 times the molecular diameter. Especially significant in the outer reaches of the atmosphere.

Frequency
In a periodic phenomenon the number of cycles occurring per unit of time, or which would occur per unit of time if all subsequent cycles were identical with the cycle under consideration. The frequency is the reciprocal of the period. The unit is usually the cycle per second.

Frequency, Basic
That frequency of a periodic quantity which is considered to be the most important. In a driven system it is generally the driving frequency while in most periodic waves it would correspond to the fundamental frequency.

Frequency, Beat
When two signals of different frequencies are applied to a non-linear circuit, they will combine, or beat together, and give, among other components, one which has a frequency equal to the difference of the two applied frequencies. This difference frequency is known as the beat frequency.

Frequency, Carrier
(See Carrier Frequency)

Frequency Distortion
Distortion which occurs as a result of failure to amplify or attenuate equally all frequencies present in a complex wave.

Frequency, Doppler
(See Doppler Shift)

Frequency, Fundamental
(1) The lowest possible frequency of vibration of a system characterized by normal modes of vibration (e.g., a vibrating string or organ pipe).
(2) The greatest common divisor of the component frequencies of a periodic wave or quantity.
(3) The frequency of a sinusoidal quantity which has the same frequency as the periodic quantity.

Frequency, Fundamental Natural
The lowest of a set of natural frequencies.

Frequency, Infrared
In the electromagnetic spectrum the range of invisible radiation frequencies which adjoins the visible red spectrum and extends to microwave radio frequencies. (See Fig. 6.5, p. 239)

Frequency, Intermediate (IF)
In a superheterodyne radio reception, the intermediate frequency is one resulting from the combination of the received frequency with a locally generated frequency, and is usually equal to their difference. Its use facilitates amplification and detection.

Frequency Modulation
(See Modulation, Frequency)

Frequency, Natural
That frequency at which a body will vibrate if displaced and allowed to oscillate freely. A tuning fork vibrates at its natural frequency. Most vibrating systems have many natural frequencies, usually harmonics of the fundamental.

Frequency, Radio (RF)
The frequencies of electromagnetic radiation used for the transmission of radio signals through space, generally ranging from between 15,000 cycles per second, in long-wave transmission, to 36,000 mc/sec in short-wave transmission. (See Fig. 6.5, p. 239)

Frequency, Resonant
(See Resonance)

Frequency Response Analysis
A method of evaluating a control system by introducing a varying rhythmic change (e.g., alternating current) into a process or control unit to determine what effect, if any, these changes will have. It is possible to use this method of analysis to predict what the addition of new equipment will mean to the operation of a control system.

Frequency Response Function
A term which is descriptive of the performance of a component in a dynamic system, i.e., the Fourier transform of the impulse response. It is also the ratio of the Fourier transform of the network output to the Fourier transform of the network input.

Frequency Response (Method)

A technique for analyzing servo mechanism performance. It utilizes the fact that a linear system, when subjected to a sinusoidal disturbance, will demonstrate a steady state sinusoidal response of the same frequency but differing in phase and amplitude from the input. The characteristics of the servo are then defined in terms of resulting change in amplitude and the phase shift over the frequency regime of interest. This method gives stability information directly from the open-loop transfer function. (See Fig. 10.23)

Frequency, Servo Corner

(See Servo Corner Frequency)

Frequency, Subcarrier

In telemetering, an intermediate frequency that is modulated by intelligence signals and, in turn, is used to modulate the radio carrier either alone or in conjunction with subcarriers. (See Fig. 6.24, p. 258)

Fretting

Physical damage caused by chafing, rubbing, or wearing away.

Fretting Corrosion

Fretting accelerated by corrosive action.

Friction

The resistance to relative movement of two surfaces in contact with one another. The coefficient of friction is equal to the ratio of the friction force to the normal force.

Frictional Forces

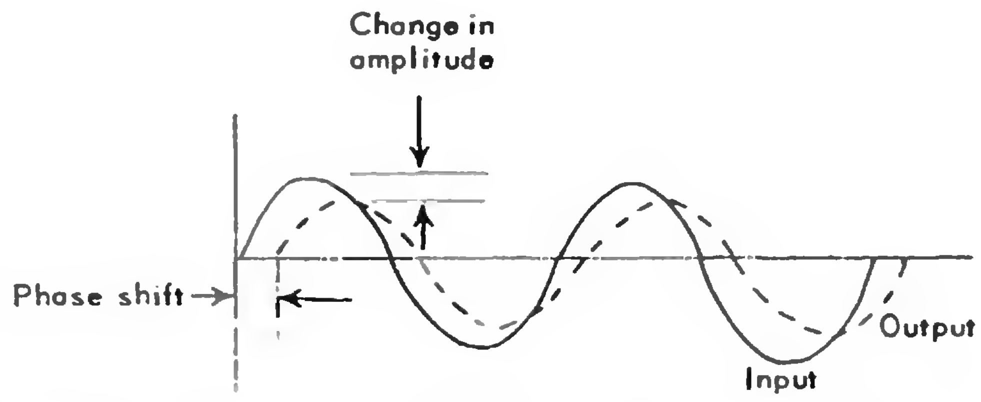
Types of forces used to overcome friction in a mechanical system:

(1) Static: A discontinuous force independent of the output until the static friction is broken.
(2) Coulomb: A constant force substantially independent of velocity and opposite to the motion.
(3) Viscous: A force proportional to velocity of the output member.

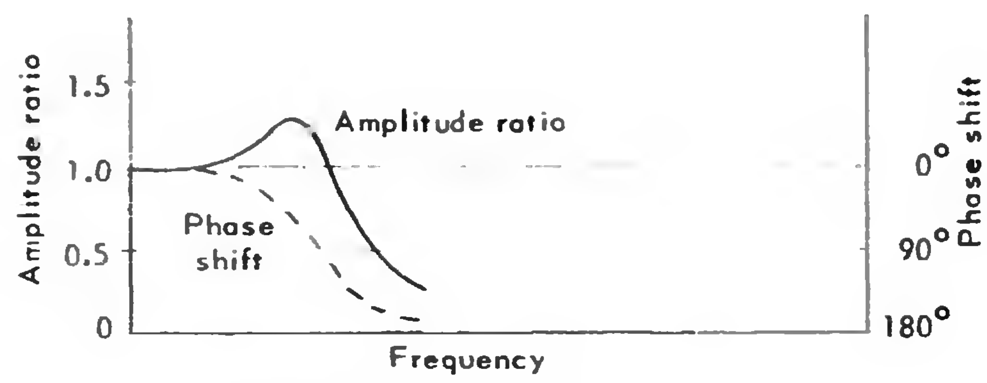
Front, Intertropical

In meteorology, the boundary between the trade wind system of the northern and southern hemispheres. It manifests itself as a fairly broad zone of transition commonly known as the doldrums.

FIG. 10.23



A. Sinusoidal output resulting from a sinusoidal input.



B. Frequency-response characteristics for a range of frequencies.

From Hartman, J.B., "Dynamics of Machinery." Copyright McGraw Hill Book Co., Inc.

Front, Occluded

In meteorology, a front along which a cold front overtakes a warm front.

Front, Pressure

(See Shock Front)

Front, Quasi-stationary

In meteorology, the ideal stationary front is seldom found in nature, but it often occurs that the frontal movement is such that no appreciable displacement takes place. The front is then said to be quasi-stationary.

Front, Secondary

In meteorology, a second front of similar nature to and following fairly closely behind a primary front. A disturbance connected therewith is called a secondary disturbance.

Front, Stationary

In meteorology, a front along which one air mass does not replace the other thus tending toward unchangeable weather.

Front-To-Back Ratio

The ratio of the effectiveness of a directional antenna, microphone or loudspeaker toward the front and toward the rear.

Front-To-Rear Ratio

In antenna terminology, the ratio of the effectiveness of a directional antenna as measured toward the front and the rear.

Fuels, Exotic
A popular term for high energy fuels.

Fuels, High Energy
Fuels with higher heat content than the hydrocarbon fuels (usually in the range of 25,000 Btu/lb). Boron compounds are frequently the basic ingredient. (See Fig. 7.1.3, p. 278)

Fuels, Zip
(1) A popular term for high energy fuels.
(2) An Air Force Project (formerly Bu Aer) with the objective of developing high-performance, non-hydrocarbon fuels. e.g., boron compound based fuels.

Full-Wave Rectifier
(See Rectifier, Full-Wave)

Functional Reliability
(See Reliability, Functional)

Fundamental Frequency
(See Frequency, Fundamental)

Fuse
A slow burning device to transmit a flame.

Fuse, Bickford
(See Bickford Fuse)

Fuse, Safety
(See Bickford Fuse)

Fuse, Miner's
(See Bickford Fuse)

Fusion, Atomic
The joining of nuclei of light atoms, such as deuterium, into a nucleus of a heavier atom, such as helium.

Fuze
That component of the armament which recognizes the optimum time for destruction of a target by a missile and initiates explosive elements leading to the detonation of the warhead at that time.

Fuze Agents
Natural phenomena utilized for the purpose of recognizing target characteristics useful for fuzing.

Fuze, Ambient
(See Ambient Fuze)

Fuze, Contact
(See Fuze, Contact)

Fuze, Impact
A fuze, as for a bomb, in which the action is initiated by the force of impact. Sometimes termed a contact fuze.

Fuze, Influence
A proximity fuze.

Fuze, Proximity
A fuze which initiates the warhead as a consequence of a determination that a target is within some specified region near the fuze, but not by contact with the target.

G

g_m
Designation for the mutual conductance of a vacuum tube.

GBL
Government Bill of Lading.

GCA
(See Ground-Controlled Approach)

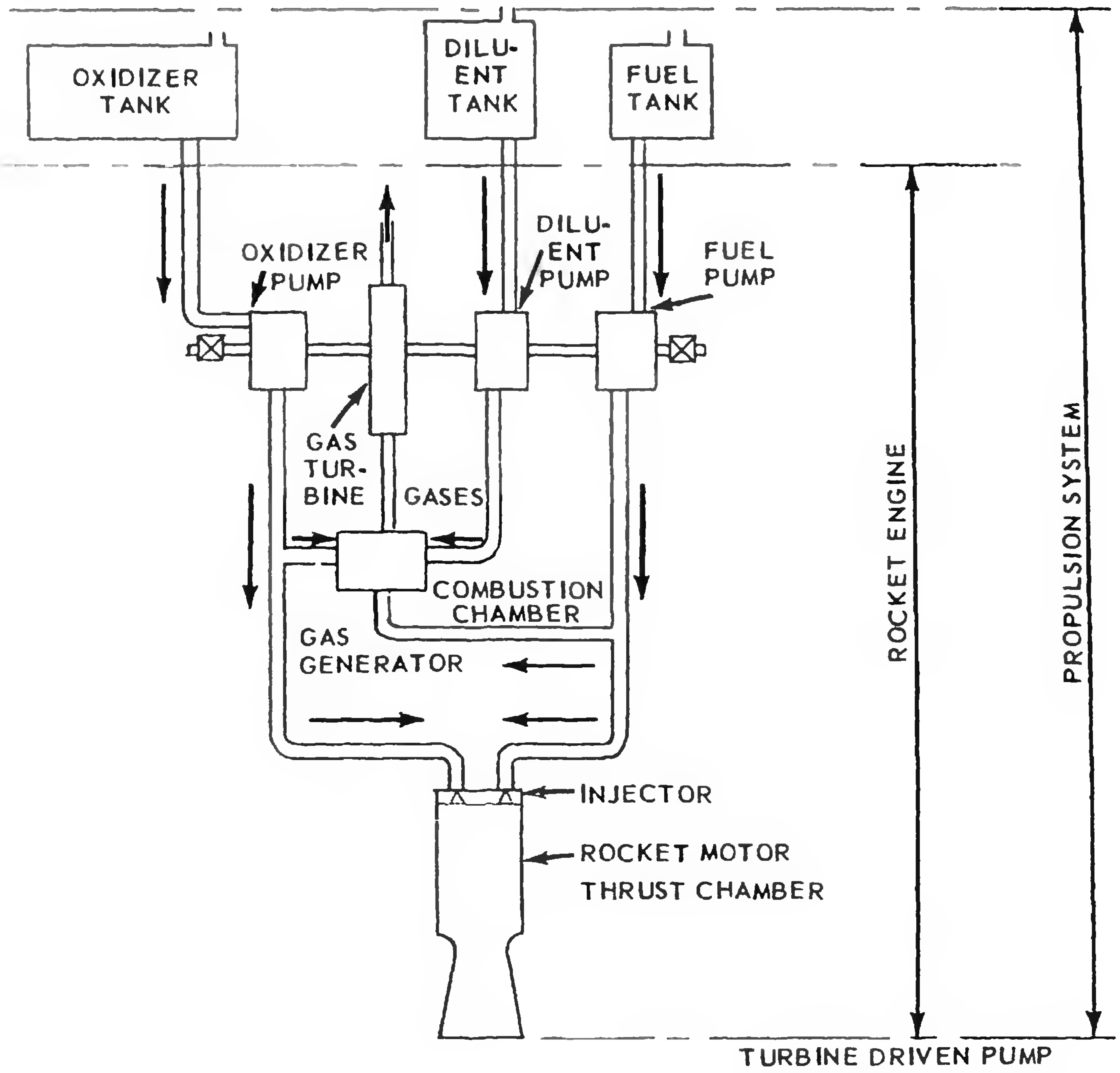
G Factor (Limit)
The ratio of the maximum acceleration that an object can withstand to the acceleration of gravity. It is equivalent to the ratio of the maximum accelerating force that the object can withstand to the weight of the object. The G factor for an object depends in part on the time duration of the accelerating force. Caution should always be exercised to ascertain, insofar as practicable, how this value was determined.

GEOREF Grid
The grid used on USAF aeronautical charts for identifying the location of any point or area in the world; the system involved in the use of this grid. Formerly World Geographic Grid. By this system the world chart is divided into 24 parallel north-south strips 15° wide numbered from A through Z (I and O omitted), beginning at the South Pole. Each quadrangle is subdivided into 15 lettered units eastward and 15 lettered units northward. These are lettered from A through Q (P and O omitted). Each one degree quadrangle is subdivided into 60 numbered minute units. Minute units may be subdivided further into decimal parts.

GFAE
(See Government-Furnished Airborne Equipment)

GFE
(See Government Furnished Equipment)

FIG. 10.53 BIPROPELLANT ROCKET JET PROPULSION SYSTEM EMPLOYING A TURBINE DRIVEN PUMP FOR PRESSURIZING THE PROPELLANTS



GFP

(See Government Furnished Property)

GM

Guided Missile. (See Missile, Guided)

GSE

(See Ground Support Equipment)

G-Weight

A weight, free to move axially in a missile frame and used to measure accelerations. (See Accelerometer)

G.Z.

(See Ground Zero)

Gain

The increase in a signal (or other quantity) as it passes through a control system or a specific control element. If a signal gets smaller, it is said to be attenuated. Alternatively, gain can mean the sensitivity of a device to changes.

Gain Margin

The number of decibels expressed in decibels below unity gain at a selected frequency, for which the phase magnitude equals 180°.

Galactic Space

(See Space, Galactic)

Gamma Radiation

(See Radiation, Gamma)

Gantry

A frame structure raised on side supports to span a missile, usually traveling on rails, which may be used for erecting and servicing large bombardment-type missiles. Can be positioned directly over the launching site and rolled away just prior to firing.

Gas Generator

(See Generator, Gas)

Gate

(1) In radar or control terminology, a sensitivity-control arrangement to pass signals only in a small, selected fraction of the principal time interval. Unwanted signals are thus rejected.

(2) In propulsion, a range of air-fuel ratios in which combustion can be initiated.

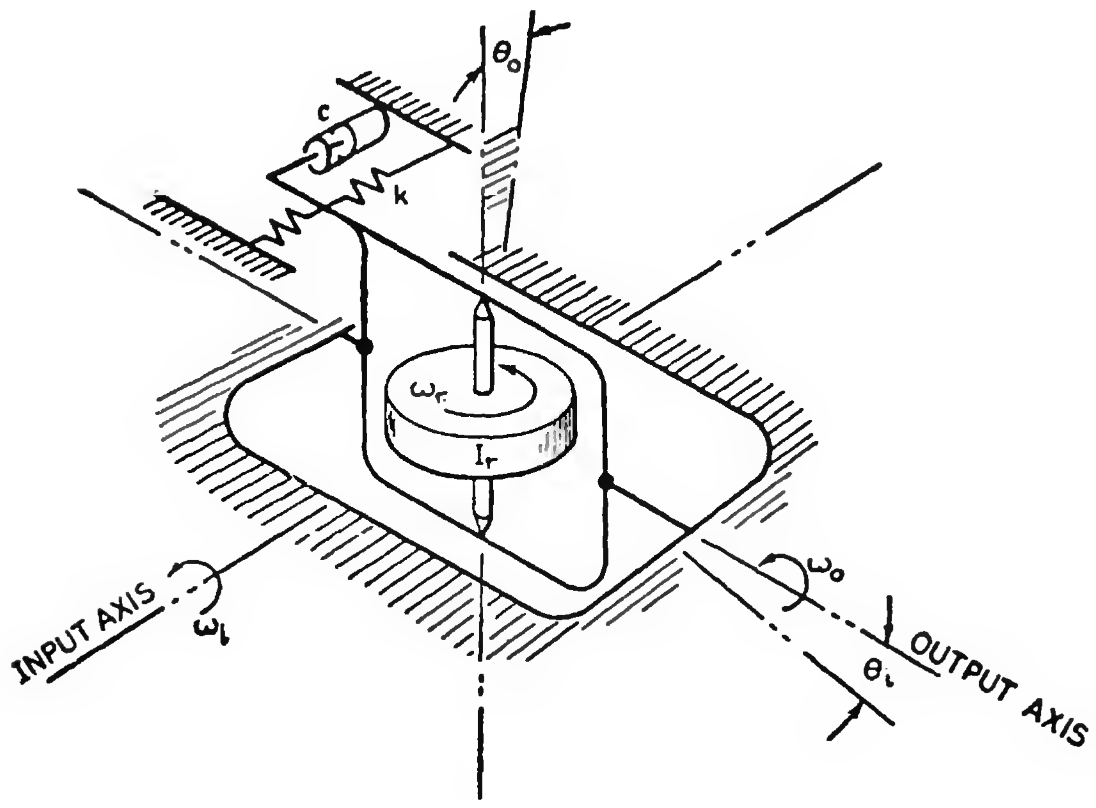
Gaussian Distribution

(See Normal Distribution)

Generator, Gas

A combustion chamber used to provide hot gases for a turbine to drive the propellant pumps of a rocket engine. Gas generators are usually operated fuel rich. (See Fig. 10.53, above)

FIG. 10.33 SIMPLIFIED DIAGRAM OF RATE GYROSCOPE OPERATION



Geopotential

The increase in potential energy per unit mass lifted from mean sea level to that point against the force of gravity. The basic unit of geopotential is the standard geopotential meter where one standard geopotential, m^1, is defined to be an increment of potential energy per unit mass equal to

$$9.80665 \text{ joules } kg^{-1} \text{ (or } m^2sec^{-1}\text{);}$$
$$\text{i.e., } 1\ m^1 = 9.80665\ m^2sec^{-2}.$$

Physical Concept One standard geopotential meter is the vertical distance through which one kilogram mass must be lifted against the force of gravity to increase its potential energy by 9.80665 joules.

Geostrophic Wind

The wind that is the result of a balanced pressure gradient and Coriolis force. Geostrophic winds blow in straight or nearly straight lines. Low pressure is to the left of the wind direction in the northern hemisphere when the observer stands with his back to the wind.

Gimbal Lock

Catastrophic malfunction of a two-axis gyroscope in which the normally orthogonal gimbals become aligned, i.e., the precession angle θ reaches 90°; usually results from excessive angular motion of the missile. (See Fig. 10.32, p. 455)

Glide Bomb

A winged missile powered by gravity. The wing loading is so high that it is incapable of flight at the speeds of modern bombardment aircraft. Such a missile therefore must be carried rather than towed.

Glint

The pulse-to-pulse variation in amplitude and apparent origin of reflected radar signal, owing to the reflection of the radar beam from a body which is changing its reflecting surface in an extremely rapid manner, such as would exist in pulses reflected from a rapidly spinning airplane propeller.

Glitter

(See Glint)

Glow Plug

An electric heating element which is used to raise a rocket propellant to its autoignition temperature.

Gnomonic Projection

A portrayal of the earth's surface in which the meridians and parallels of latitude are projected to a plane tangent to the earth at one point. e.g., north pole.

Goniometer

(1) An instrument for measuring the angles between the reflecting surfaces of a crystal or a prism.
(2) A radio receiver and directional antenna system for determining the angle of arrival of incident waves.
(3) Autosyn phase shifters driven by a common gear train.

Go-No-Go Testing

A testing technique in which a signal is obtained which indicates that the system either is or is not functioning properly. No measure of performance is given and no degradation of operating characteristics can be measured. Go-no-go testing may be made open or closed loop and on any level of assembly.

Government-Furnished Airborne Equipment (GFAE)

Equipment furnished by the government for installation in airborne vehicles and for which the title remains with the government.

Government-Furnished Equipment (GFE)

Equipment furnished by the government for an end item and for which the title remains with the government.

Government-Furnished Property (GFP)
Equipment or material provided to a contractor by the government to be used by the contractor in the development, production or testing of items to be delivered to the government or to be incorporated by the contractor into equipment being built, assembled or modified by the contractor for delivery to the government. (See Government-Furnished Airborne Equipment (GFAE))

Grain
A single mass of solid propellant, either cast or extruded in one piece, or composed of cemented or compressed pieces.

Grain, Case Bonded
In solid rocket usage, a grain cemented or bonded to the case or container to prevent burning on the surface adjacent to the container.

Grain, Restricted Burning
(See Restricted Burning Grain)

Grain, Star
(See Star Grain)

Grass
A slang term denoting the visible effects of random noise on an oscilloscope display.

Gravitational Anomalies
Irregular distribution of the gravitational field over the earth's surface.

Gravity (Non-Rotating Earth)
The acceleration force exerted on terrestrial bodies by a fictitious earth which is homogeneous, stationary, isolated, and spherical.

Gray Body
A radiator whose spectral emissivity remains constant through the spectrum, being in a constant ratio, less than unity, to that of a complete radiator (black body) at the same temperature.

Gray Code
In digital computer applications, a modified binary code used for analog-to-digital conversion. The principle of operation is based on the change of only one element in a system at a time when passing from one digit to the next. Also termed cyclic binary or reflective code.

Great Circle Course
The shortest path between two points on a spherical earth. The path is coincident with the circular arc whose radius is equal to that of the earth, and whose center of curvature is located at the center of the earth.

Grid
An electrode mounted between the cathode and the anode of a radio or electronic tube to control the flow of electrons from cathode to anode. The grid electrode is usually either a cylindrical-shaped wire screen or a spiral of wire through which electrons can readily move.

Ground
An electrical conductor connected to earth, or a large conductor whose potential is taken as zero: e.g., the metallic frame of a missile. A ground may be undesirable, inadvertent, or accidental path taken by an electrical current; or it may be the deliberate provision of conductors well connected to the ground by means of plates buried therein, or similar devices.

Ground Antenna Data Link System
Electronic equipment that provides an RF link between test equipment and equipment under test.

Ground-Controlled Approach (GCA)
A method of landing aircraft in poor visibility by directing the operation with the aid of a ground radar station.

Ground Return
(See Clutter, Radar)

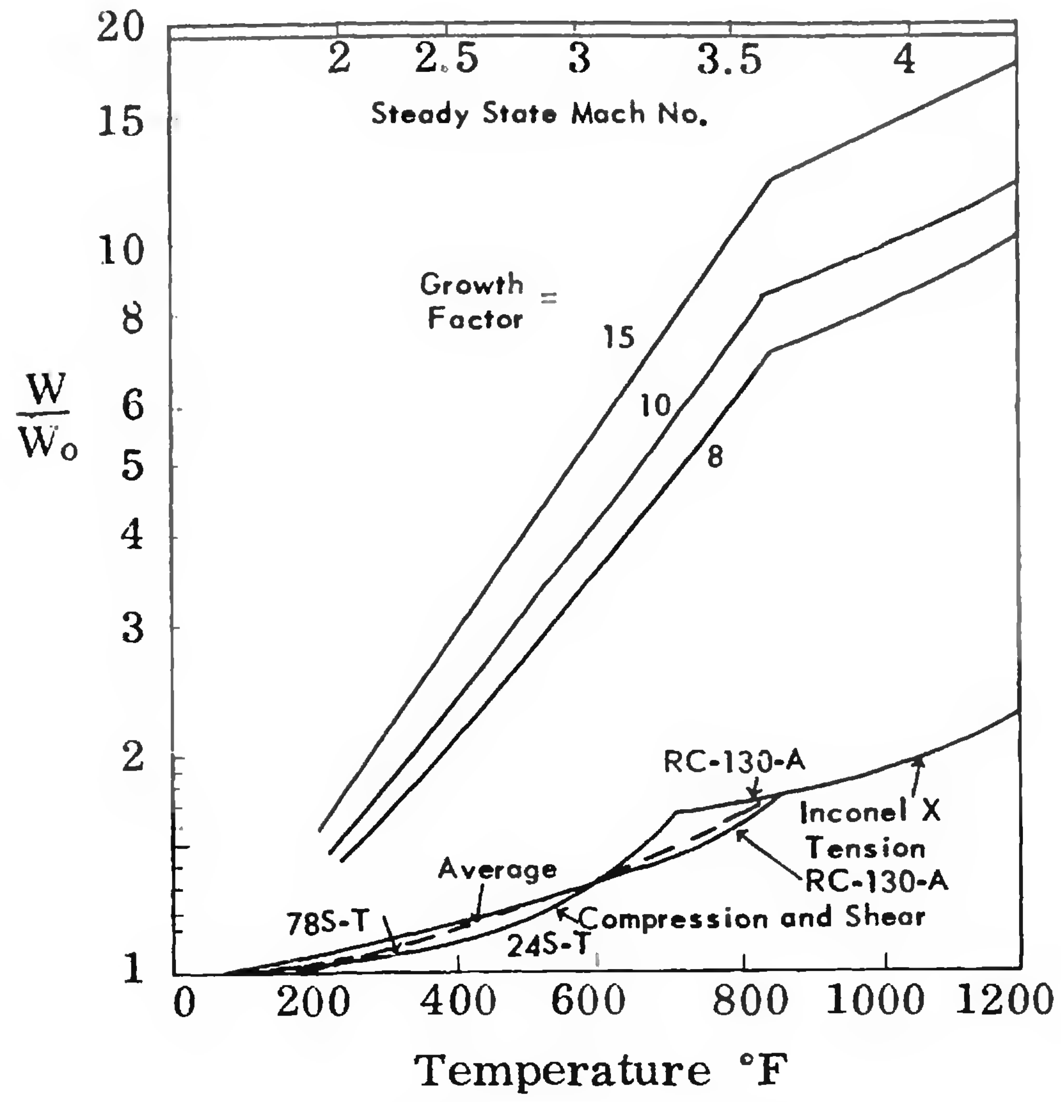
Ground (Sea) Clutter
Unwanted radar echoes from terrain (or sea) in the vicinity of a target.

Ground Shock
The magnitude, direction, and duration of the shock at a given point on the surface or below the surface of the earth resulting from a nuclear explosion of a given magnitude and burst position.

Ground Speed
The horizontal component of the velocity of an aircraft or ship relative to the earth's surface beneath it.

Ground Support Equipment (GSE)
All ground equipment that is part of the complete weapon system and that must be furnished to insure its support.

FIG. 10.24 GROWTH FACTOR



Relative weight of aircraft designed for thermal flight (W) as compared to same aircraft designed on basis of room temperature (W_0). In this comparison, 78S-T was assumed for the room-temperature aircraft while for the thermal-flight aircraft the average trend based on the most efficient materials for a given temperature was used (Gerard).

Included are all implements or devices required to inspect, test, adjust, calibrate, appraise, gage, measure, repair, overhaul, assemble, disassemble, transport, safeguard, record, store, actuate, service, launch, and otherwise support and maintain the functional operating status of a weapon system, subsystem, end item, or component. Test GSE is ground support equipment used to support the missile development program. Operational GSE is ground support equipment used in the operational weapon system.

Ground-To-Air Missile

(See Missile, Ground-to-Air; Missile, Guided; Model Designation)

Ground-to-Ground Missile

(See Missile, Ground-to-Ground; Missile, Guided; Model Designation)

Ground Waves

(See Waves, Ground)

Ground Zero (G.Z.)

That point on the earth's surface directly below, at, or above where an atomic bomb is detonated.

Growth Factor

A factor defining the increase in weight, volume, power, or any other parameter caused by the addition of some feature: e.g., an increase in a missile payload causes an extra increase in gross weight. The ratio of the latter to the former is the growth factor. (See Fig. 10.24)

Guard Band

In electronic propagation, a narrow band of unassigned frequencies located between assigned frequency channels used to prevent cross talk.

Guidance

Concerning missiles, the processes of intelligence gathering and maneuvering required to reach a specified destination, with special connotation on the flight path and on the information for determining the proper course whether computed externally or within the missile itself. (See Fig. 10.25)

Guidance, Beam Rider

A system for guiding missiles which utilizes a beam directed into space, such that the center of the beam axis forms a line along which it is desired to direct a missile. The beam, which may be either fixed in elevation and

FIG. 10.25 SIMPLIFIED BLOCK DIAGRAM OF GENERALIZED GUIDANCE SYSTEM

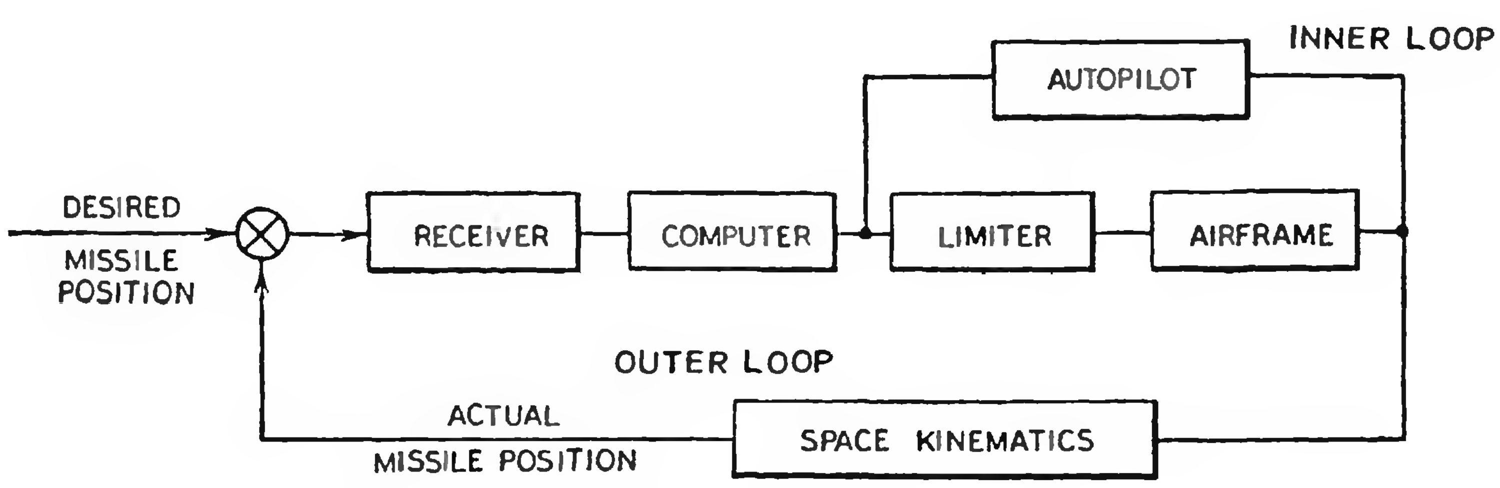


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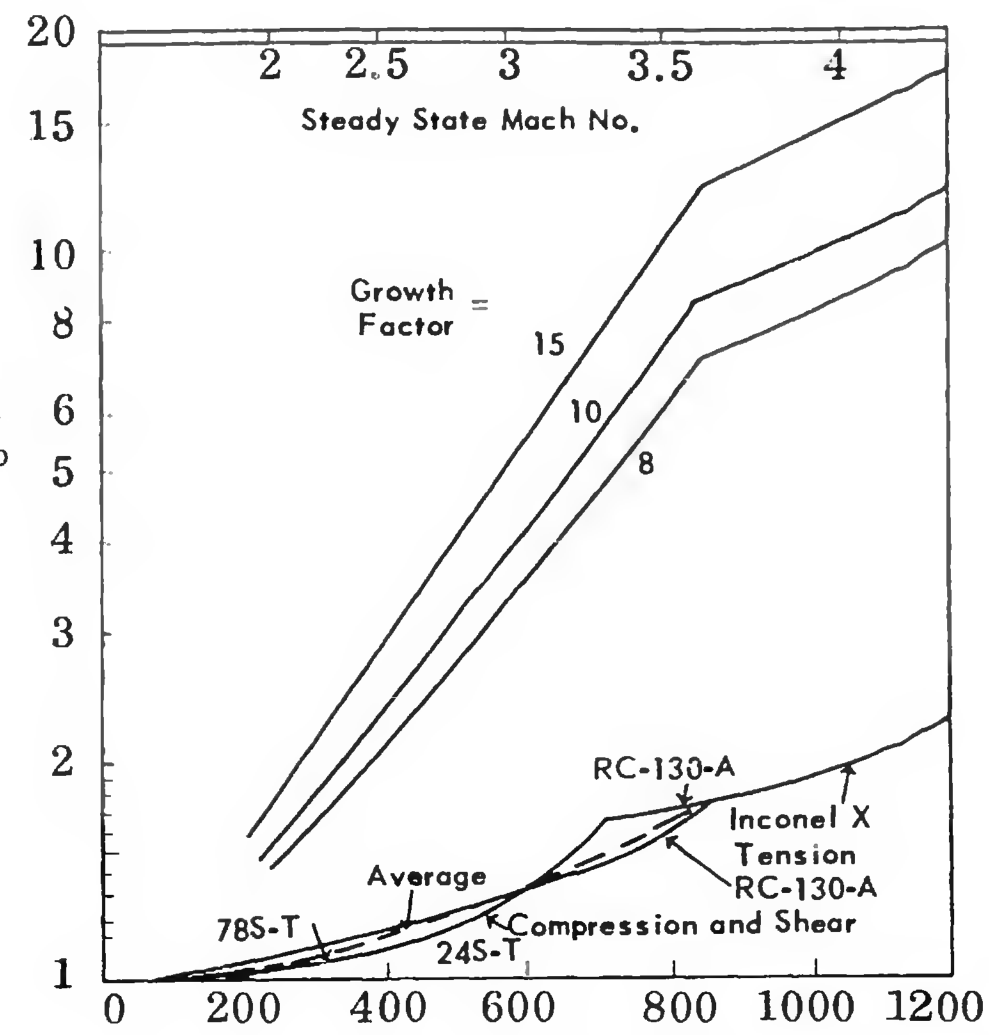
FIG. 10.24 GROWTH FACTOR



Relative weight of aircraft designed for thermal flight (W) as compared to same aircraft designed on basis of room temperature (W_o). In this comparison, 78S-T was assumed for the room-temperature aircraft while for the thermal-flight aircraft the average trend based on the most efficient materials for a given temperature was used (Gerard).

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A system for guiding missiles which utilizes a beam directed into space, such that the center of the beam axis forms a line along which it is desired to direct a missile. The beam, which may be either fixed in elevation and

FIG. 10.25 SIMPLIFIED BLOCK DIAGRAM OF GENERALIZED GUIDANCE SYSTEM

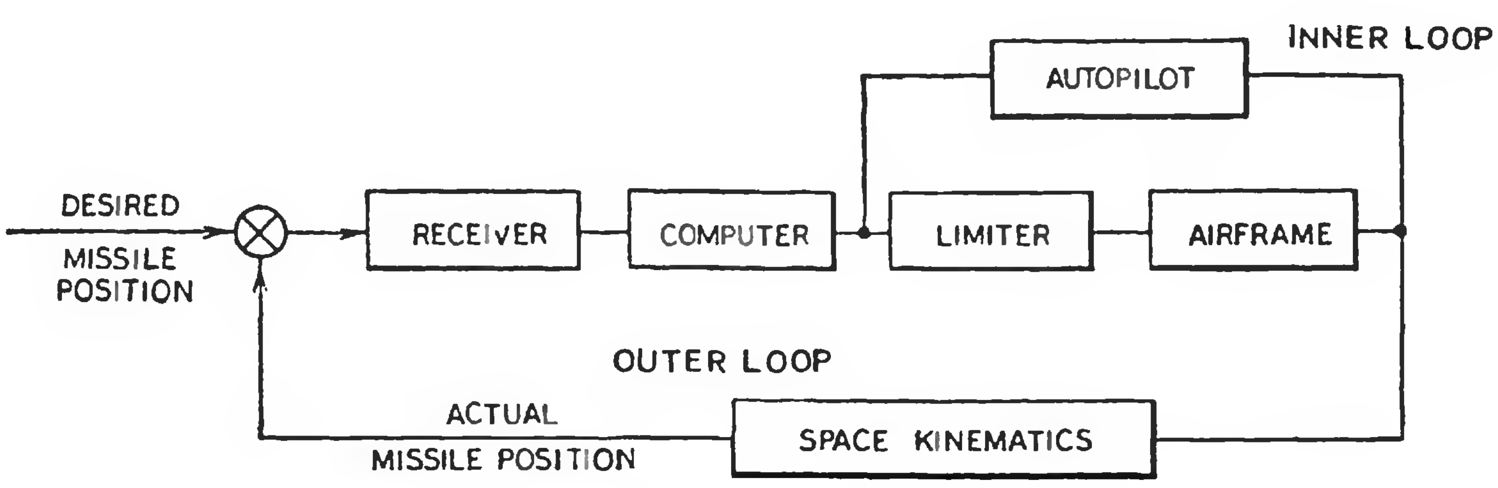
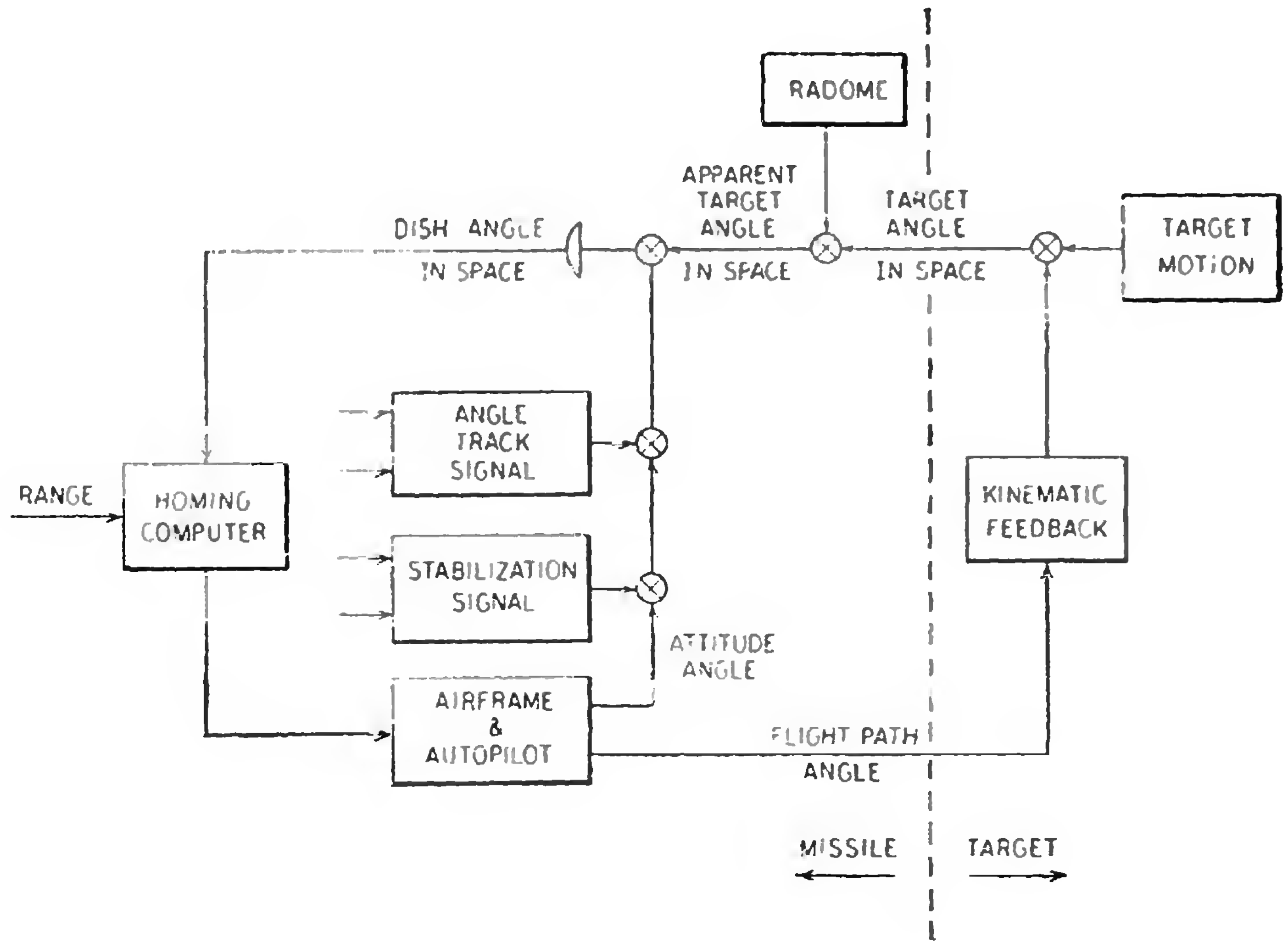


FIG. 10.26 GENERAL HOMING GUIDANCE SYSTEM



azimuth or moving, may be a radar beam, a light beam, or a beam of some other type. Equipment is built into the missile, such that the missile can determine when it is in the center of the beam or can determine the direction and magnitude of the error when it has deviated therefrom. Also built into the missile are suitable electronic circuits, servo motors, aerodynamic surfaces, and/or other equipment, such that the missile by its own initiative, will return toward the center of the beam when it has deviated therefrom for any reason. (See Fig. 10.9 and 10.10, p. 405)

Guidance, Celestial

(See Navigation, Celestial)

Guidance, Celestial-Inertial

A system in which the basic inertial guidance is corrected by supplementary position and/or velocity information as obtained from celestial observations: e.g., optical or radio star trackers.

Guidance, Command

A guidance system wherein intelligence transmitted to the missile from an outside source causes the missile to traverse a directed path in space. (See Fig. 10.13, p. 415)

Guidance, Homing

A guidance system by which a missile steers itself towards a target by means of a self-contained mechanism which is activated by some distinguishing characteristic of the target. (See Fig. 10.26)

Guidance, Homing, Active

A system of homing guidance wherein both the source for illuminating the target and the receiver are carried within the missile. (See Fig. 10.27)

Guidance, Homing, Passive

A system of homing guidance wherein the receiver in the missile utilizes natural radiations from the target. (See Fig. 10.28)

Guidance, Homing, Semiactive

A system of homing guidance wherein the receiver in the missile utilizes radiations from the target which has been illuminated from a source other than the missile. (See Fig. 10.29)

Guidance, Inertial

A system independent of information obtained from outside the missile, the sensitive elements of which system make

FIG. 10.27 TRACKING LOOP OF AN ACTIVE HOMING SYSTEM

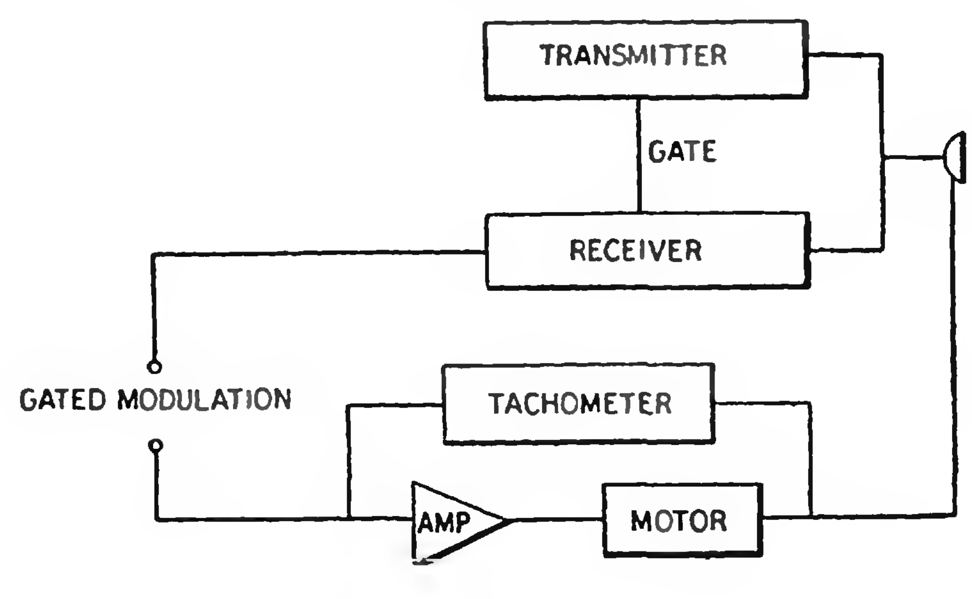
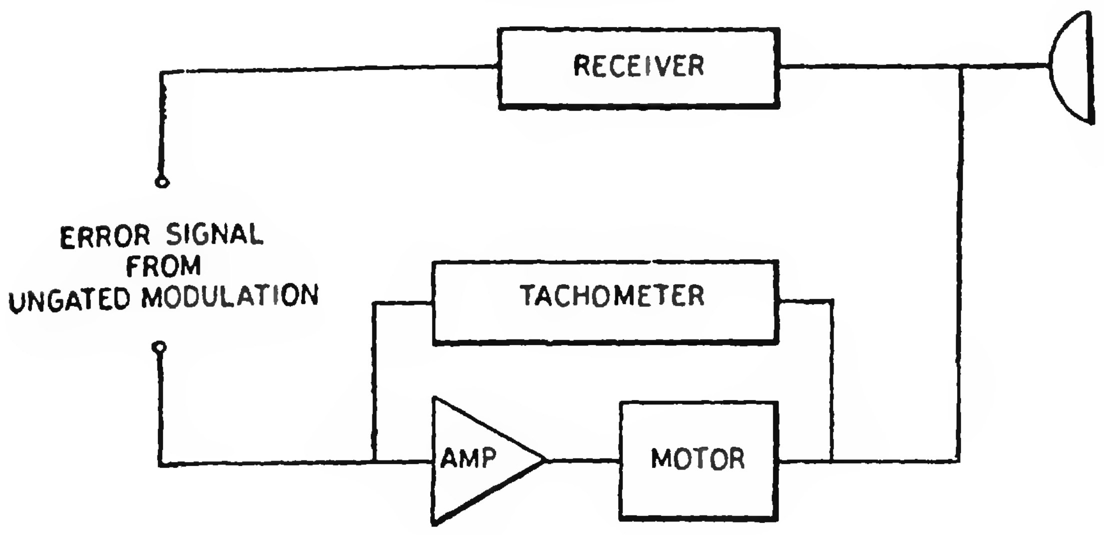


FIG. 10.28 TRACKING LOOP OF A PASSIVE HOMING SYSTEM



use of the principle of Newton's second law of motion. (See Fig. 10.30, p. 454)

Guidance, Midcourse

The guidance applied to a missile between the termination of the launching phase and the start of the terminal phase of guidance.

Guidance, Preset

A technique of missile guidance wherein a predetermined path is set into the guidance and control mechanism of the vehicle and cannot be adjusted after launching. A missile using preset guidance is not a true guided missile.

Guidance, Radio Inertial

A command type of guidance system consisting essentially of (a) a radar tracking unit; comprised of radar equipment on the ground, one or more transponders in the missile, and necessary communication links to the guidance station; (b) a computer that accepts missile position and velocity information from the tracking system, and furnishes to the command link appropriate signals to steer the missile; (c) a command link which consists of a transmitter on the ground and an antenna and receiver on the missile; actually, the command link is built into the tracking unit; (d) an inertial system for partial guidance in case of radio guidance failure or to provide more "up-to-date" data for correcting the radar guidance information. (See Fig. 10.31, p. 454)

Guidance Station

A ground or ship facility that has the capability of directing missiles while in flight.

Guidance, Stellar

(See Navigation, Celestial)

Guidance System, Inertial

A dead-reckoning missile guidance system that employs sensitive elements which respond to the earth's gravitational field and to inertial effects in accordance with the Newtonian laws of motion. The system therefore is not dependent on information obtained from transmitters outside the missile. (See Fig. 10.30, p. 454)

Guidance System, Inertial Gravitational

A system which is independent of information other than gravitational effects, obtained from outside the missile. The sensitive elements of the system make use of the principle of Newton's second law of motion.

Guidance System, Homing

(See Homing Guidance System)

Guidance Tapes

Magnetic or paper tapes that are placed in a missile or its computer, and on which there previously has been entered information needed to program

FIG. 10.29 TRACKING LOOP OF A SEMIACTIVE HOMING SYSTEM

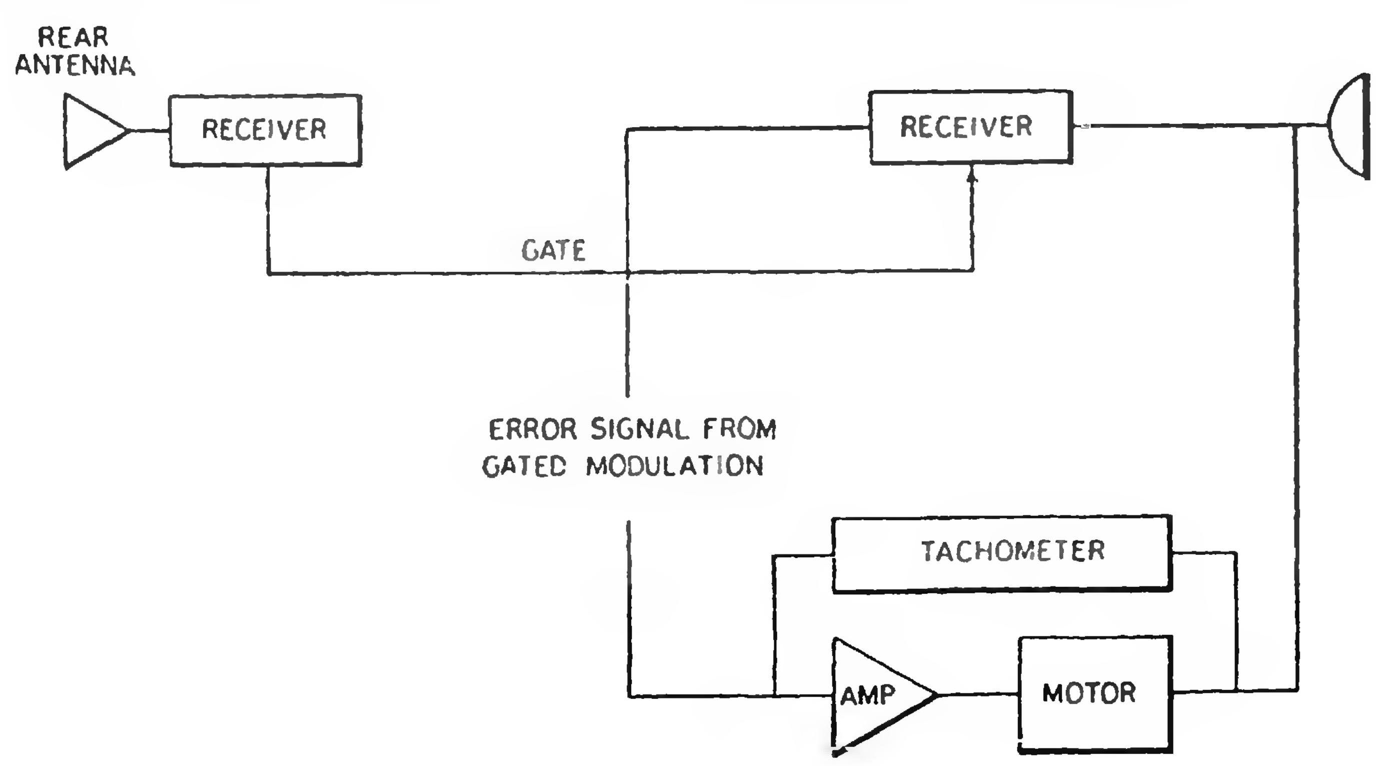
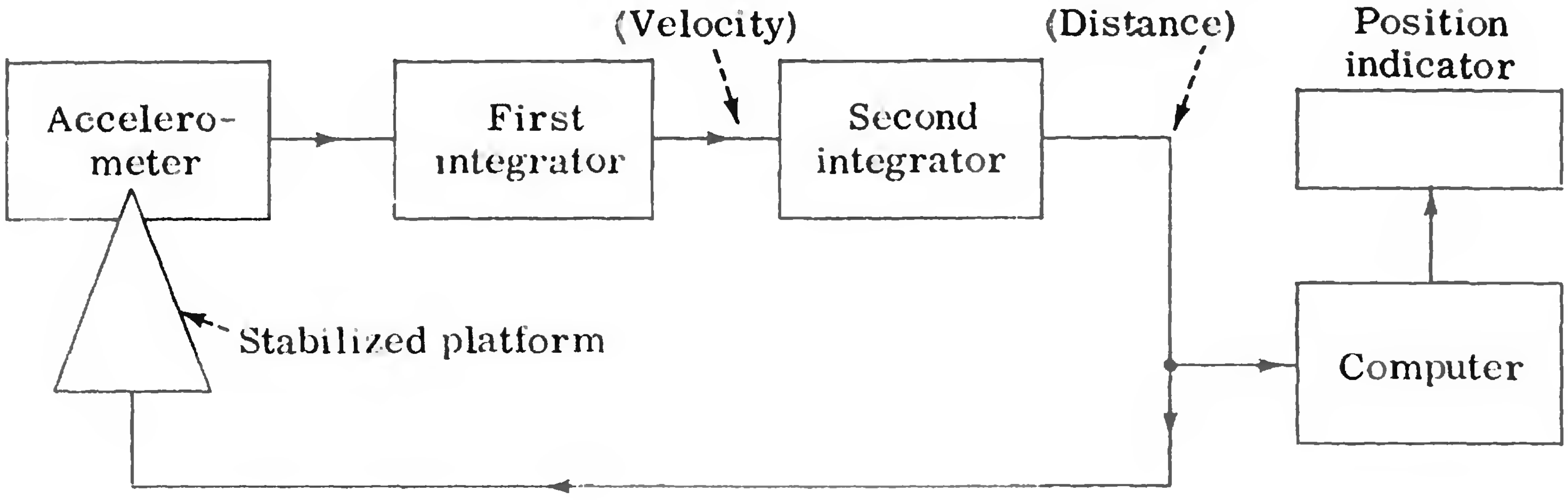


FIG. 10.30 SCHEMATIC OF INERTIAL GUIDANCE SYSTEM



desired events in the missile during flight.

Guidance, Terminal

The guidance applied to a missile between the termination of the midcourse guidance and impact with or detonation in close proximity to the target.

Guidance, Terrestrial Reference

A technique of missile control wherein the predetermined path set into the control system of a missile can be followed by a device in the missile which reacts to some property of the earth, such as magnetic or gravitational effects.

Guidance, Track-Command

A method of missile guidance wherein both target and missile are tracked by separate radars and corrective commands are sent to the missile. (See Fig. 10.13, p. 415)

Guided Ballistic Missile

(See Missile, Guided Ballistic)

Guided Missile

(See Missile, Guided)

Guided Missile System

(See Missile System, Guided)

Gusts

Transient but rapid fluctuations of wind velocity. Gusts are the result of turbulent air flow. Gusty winds usually vary radially in direction.

Gutter

In an air-breathing engine, the portion of a flame holder which is grooved to improve stability of the flame holding operation. (See Fig. 10.48, p. 443)

Gyropilot

(See Automatic Pilot)

Gyroscope

A wheel or disc, mounted to spin rapidly about an axis and also free to rotate

FIG. 10.31 RADIO INERTIAL; DOPPLER INERTIAL; RADAR INERTIAL GUIDANCE SYSTEM SCHEMATIC

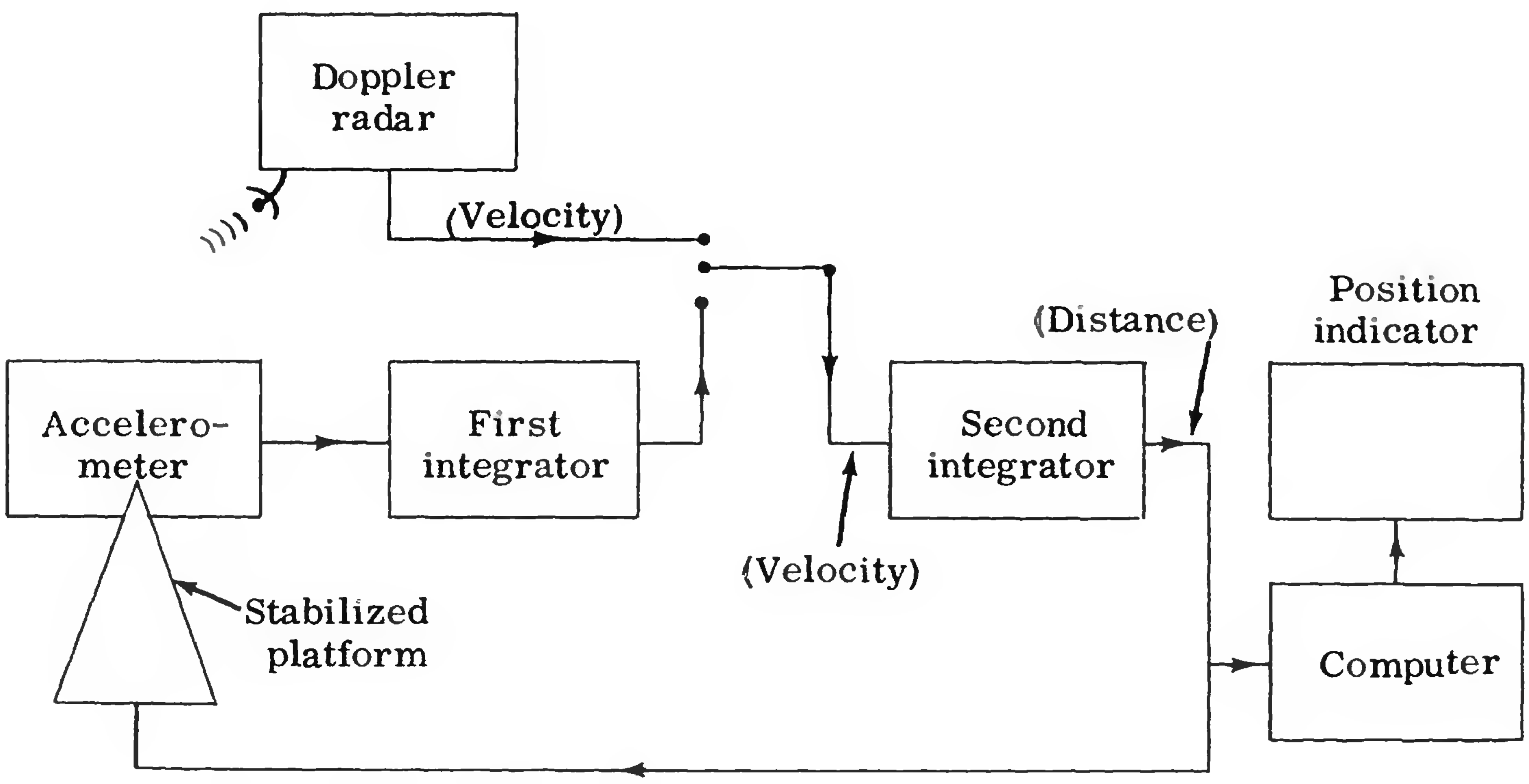
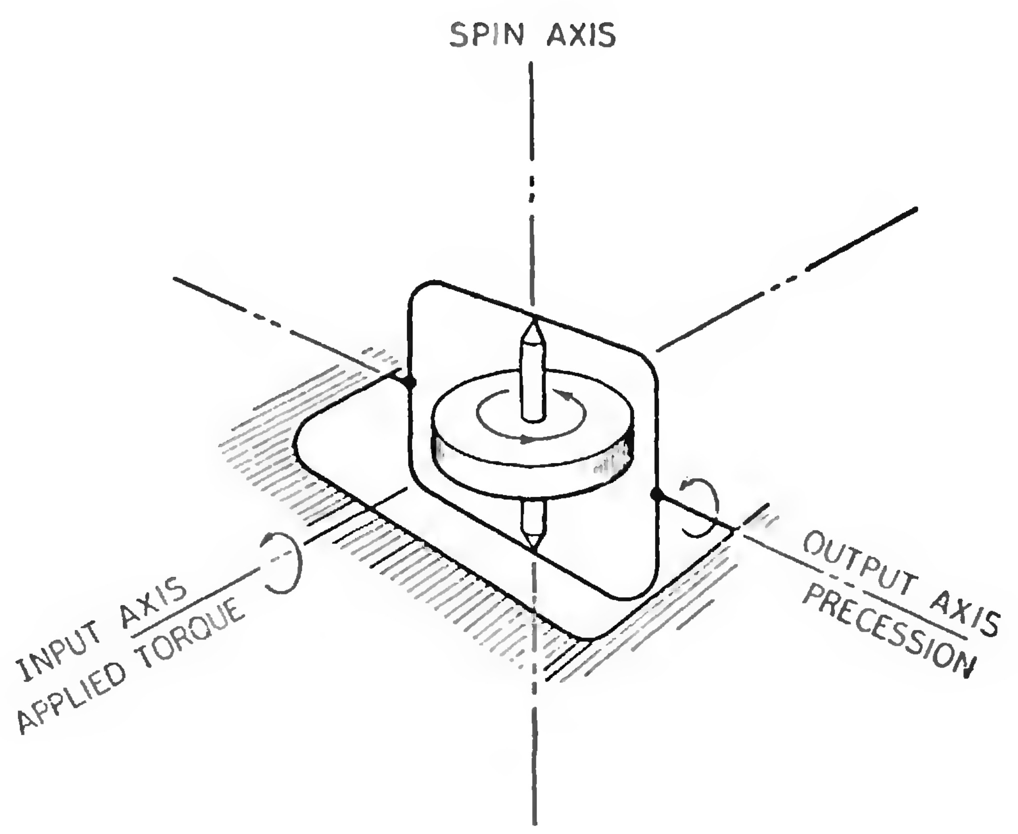


FIG. 10.32 FREE GYRO SHOWING GYROSCOPIC PRECESSION



about one or both of two axes perpendicular to each other and to the axis of spin. The spinning gyroscope either offers considerable resistance, depending upon its angular momentum to any torque, which would tend to change the direction of the spin axis or, if free, changes its spin axis in a direction perpendicular both to the torque and to the original spin axis. (See Fig. 10.32)

Gyroscope, Body Mounted

(See Body Mounted Gyroscope)

Gyroscope, Directional

A gyroscopic instrument for indicating direction. It contains a free gyroscope which holds its position in azimuth and thus indicates angular deviation from the course.

Gyroscope, Displacement (Free Attitude)

A sensing instrument for establishing a space-reference for a missile which makes use of a gyroscope's inherent characteristic of attempting to maintain its spin axis fixed in space. The gyroscope is mounted on gimbals which give it two-degrees of freedom. (See Fig. 10.32)

Gyroscope Drift

The difference between the actual and theoretical line of direction of a gyroscope due to three general sources:

(a) Unbalance - due to unsymmetry of manufactured parts, temperature, etc.
(b) Bearing Friction - due to gimbal friction. Spin axis friction does not cause precession if the friction is symmetrical.
(c) Gimbal inertia.

Gyroscope, Foucault

The gyroscope wheel is supported by gimbals such that it is allowed to turn freely about any axis and the parts are balanced to prevent gravity from exerting a torque on the wheel.

Gyroscope, Free

A gyroscope mounted in two or more gimbal rings so that its spin axis is free to maintain a fixed orientation in space.

Gyroscopic Horizon

A gyroscope instrument that indicates the lateral and longitudinal attitude of the airplane by simulating the natural horizon. A single degree of freedom gyroscope.

Gyroscope, Integrating

An adaptation of the familiar rate gyroscope; both have only a single degree of freedom. The restraining force exerted by the viscous damping is proportional to the gyroscope precession rate instead of the displacement. (See HIG (Gyro))

Gyroscope, Integrating (Pendulous) Accelerometer

A gyroscope capable of sensing and integrating a linear acceleration to obtain the resultant velocity. It is unsymmetrically suspended so that acceleration produces a precession force resulting in an angular displacement of the gyroscope axis proportional to the time integral of the acceleration.

Gyroscope, Precession

The force-motion relationship of a spinning gyroscope resulting from Newton's law of motion: "The time rate of change of angular momentum of a body about any given axis is equal to the torque applied about the given axis."

$$T = I \omega_r \Omega$$

where T = torque
I = inertia of the gyro rotor about the spin axis
ω_r = rotor speed
Ω = angular velocity about the output axis

Precession is always in such a direction as to align the direction of rotation of the rotor with the direction of rotation of the applied torque. (See Fig. 10.32, p. 455)

Gyroscope, Rate

A gyroscope with a single gimbal mounting, such that rotation about an axis perpendicular to the axis of the gimbal and to the axis of the gyroscope produces a precessional torque proportional to the rate of rotation. (See Fig. 10.33, p. 449)

Gyroscope, Single Degree of Freedom

A gyroscope with two rotational axes but a single gimbal axis. The geometric position at any instant is expressed by one number. If the restraint on the gimbal is a spring, the unit is classed as a rate gyroscope. If the restraint is viscous, the unit is classed as an integrating or displacement gyroscope.

Gyroscope-stabilized Platform

In inertial guidance, a gyroscopically stabilized platform for mounting accelerometers to maintain them fixed either in a space or earth reference system despite changes in missile position and attitude. (See Fig. 10.34)

Gyroscope Torqueing

The process of applying an external signal to the gimbals of a displacement gyroscope as a means of programming the position of the reference axes. Torquers may be operated on AC or DC.

Gyroscope Torquer Hysteresis

The residual torque in a DC torquer resulting from the magnetic memory of the torque generator when the excitation is removed.

Gyroscope, Unbalanced

A gyroscope which is unbalanced to make it sensitive to acceleration. Any acceleration about the sensitive axis produces gyroscope precession (displacement) at a rate proportional to acceleration. This makes the total angle of gyroscope displacement proportional to the integral of acceleration, hence proportional to vehicle velocity. (See Gyroscope, Integrating (Pendulous))

Gyro Transfer Table (GTTS)

A portable precision gyro instrument designed to transfer physically the direction of vertical and the true north from a reference instrument (normally a Ship's Inertial Navigation System) to another part of the Ship's Navigation or Fire Control Systems or to a missile.

H

HGE

Handling, Ground Equipment

HIG (Gyro) Hermetically-sealed Integrating Gyroscope

An integrating gyroscope in which viscous damping replaces the spring restraint of the rate gyroscope. As a result, the restraining force exerted by the viscous damper is proportional to gyroscope precession rate, instead of being proportional to precession displacement, as in a rate gyroscope. (See Fig. 10.35)

HVAP

High-velocity, armor-piercing rocket.

HVAR

High-velocity aircraft rocket.

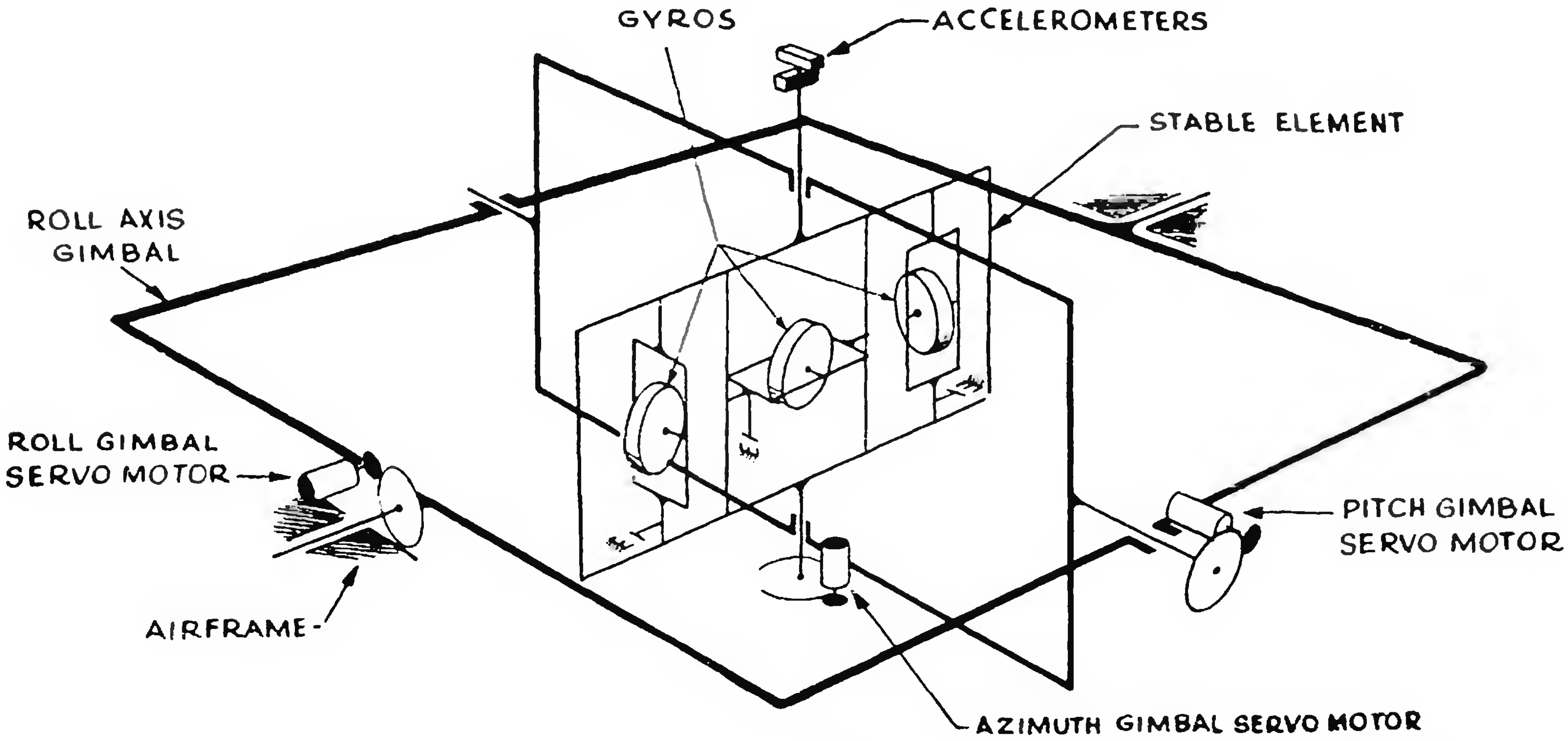
H-Vector

The vector representing the magnetic component of an electromagnetic field. (See E-Vector)

Hail

Pellets of ice ranging from about 1/16 in. in diameter to as much as 4 or 5 in. Hailstones are often transparent, but more frequently are translucent, being formed of alternate layers of clear and opaque ice. Hail usually falls from thunderstorms.

FIG. 10.34 SCHEMATIC OF A GYROSCOPE STABILIZED PLATFORM ON WHICH ARE MOUNTED LINEAR ACCELEROMETERS



Half Life

Time required for a radioactive substance to lose half of its activity by radioactive decay, i.e., time required for a radioactive element to change half its original mass into a new, and usually less radioactive, element.

Half Power (Point)

In an antenna pattern, the power on each side of the main lobe which is 3 db down.

Half Wave Antenna

(See Antenna, Dipole)

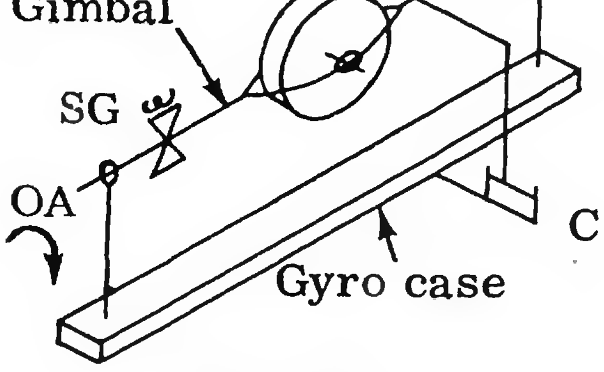
Hangfire

The delayed ignition of a rocket propellant or igniter.

Hardness

(1) A term which qualifies a target's vulnerability to damage, particularly from a nuclear explosion.

FIG. 10.35 SCHEMATIC OF INTEGRATING GYROSCOPE



HIG Gyro

(2) The property of an installation, facility, or equipment that will prevent an unacceptable level of damage resulting from aerial bombardment.

Hard Points

Structurally reinforced areas on a missile's exterior surface which are suitable for supporting it during handling and stowage.

Hard Structure

A structure designed to withstand nuclear weapon effects of a stated magnitude.

Hard Tube

A vacuum tube that has been evacuated to a high degree.

Hardware, Body

(See Body Hardware)

Hardware Specification

(See Equipment (Hardware) Specification)

Harmonic

A component frequency of a periodic quantity which is an integral multiple of the fundamental frequency.

Harmonic Distortion

(See Distortion, Harmonic)

Hartley

In communication theory, a unit of information which is generally defined as being equal to 3.219 bits.

Hash

Slang term for electrical noise produced by a mechanical vibrator or by the brushes of a generator or motor.

Heading

The direction in which a missile or vehicle heads at any particular moment, usually measured in an earth reference system.

Heat Shield

The protective structure necessary to prevent destruction of a reentry body incident to aerodynamic heating. A material sink may be used to absorb heat or oblating materials may similarly be used.

Heat Sink

A device which absorbs heat energy.

Heat, Solar

Heat received from the sun which is the primary source of energy for the earth. On a normal day solar radiation is about 120 Btu/sq ft/hr; maximum anticipated is 360 Btu/sq ft/hr.

Heat Transfer

The heat influx of a high speed missile incident to aerodynamic heating.

Heavy Water

Water in which the hydrogen of the water molecule consists entirely of the heavy hydrogen isotope of mass two. It is used as a moderator in certain type of nuclear reactors.

Helium, Liquid Forms I and II

Liquid helium undergoes a change in its physical properties at 2.189°K, the so-called lambda-point. The form stable between the critical temperature and the lambda-point is called liquid helium I, and that stable between the lambda-point and absolute zero is called liquid helium II. Since the transformation is one of higher order, without latent heat at the lambda-point, the two liquid forms are never co-existent. The lambda-transformation does not occur in liquid helium with isotopic weight 3.

Heterodyne

Two alternating currents of different frequency, when "mixed" in a non-linear impedance device such as a rectifier, generate a current having the sum-and difference-frequencies, either or both of which may be selected by properly tuning or filtering the output. This phenomenon is known as heterodyne action, and is put to practical use in the superheterodyne radio receiver circuit. (See Frequency, Intermediate)

Heterogeneous Propellant

(See Propellant, Heterogeneous)

Heterogeneous Reactor

(See Reactor, Heterogeneous)

Heterosphere

That part of the atmosphere above the homopause (50 miles) as classified by Chapman (Composition Atmosphere).

High Energy Fuels

(See Fuels, High Energy)

High-Flux Reactor

(See Reactor, High Flux)

High Order Detonation

(See Detonation)

High-Pass Filter

(See Filter, High-Pass)

Holdback

A device or mechanism whose function is to retain the missile on the launcher until it is desired to launch and until certain conditions, requisite to successful launching, are met.

Homer

(See Homing Guidance System; Seeker, Target)

Homing Guidance System

A guidance system by which a missile steers itself toward a target by means of a self-contained mechanism which is activited by some distinguishing characteristic of the target. The homing guidance systems fall under one of three general types: active homing, semi-active homing, and passive homing. (See Guidance, Homing; Guidance, Active; Guidance, Passive; Radar Illumination)

Homing, Interferometer

A homing guidance system in which target direction is determined by comparing the phase of the echo signal as received at two antennas precisely spaced a few wavelengths apart.

Homing, Radar

(See Radar, Homing)

Homing, Semi-active

(See Radar Illumination)

Homogeneous Propellant

(See Propellant, Homogeneous)

Homogeneous Reactor
(See Reactor, Homogeneous)

Homopause
The altitude (50 miles) at which the composition of the atmosphere changes (Chapman nomenclature).

Homosphere
That part of the atmosphere from Sea Level up to the homopause (50 miles) as classified by Chapman (Composition Atmosphere).

Horizon, Radar, Radio
The locus on the earth's surface beyond which high frequency electromagnetic signals from a given source cannot be propagated. This limitation arises from the inability of such signals to propagate in other than a straight line with the curvature of the earth including consideration of diffraction. (See Fig. 6.7, p. 241)

Horizon Tracker
A device for establishing the vertical by precisely tracking the visible horizon simultaneously in mutually orthogonal directions.

Humidity
(1) Absolute Humidity indicates the amount of water vapor in the air in quantitative terms, e.g., pounds of water per pound of dry air.
(2) Relative Humidity is the ratio of the amount of water vapor in the air to the maximum amount which air at any given temperature can retain without precipitation. Relative humidity is usually expressed in terms of percent. The temperature at which relative humidity is measured is necessary to give meaning to the measurement.

Hunting
The undesirable oscillation of an automatic-control system such that the controlled variable swings on both sides of the predetermined reference value without settling on it.

Hurricane
A term applied to extra-tropical storms in the Atlantic Ocean. Over all oceans, near the equator, with the exception of the South Atlantic, there develop occasionally tropical cyclones which are intense vortices covering relatively large areas. As they move away from the equator they usually intensify. All are the same type of storm. Surface pressure in a hurricane is very low at the center or eye of the storm but rises rapidly outward toward the periphery. Because of the large pressure gradient, winds are of high velocity, blowing counter-clockwise in the northern hemisphere and clockwise south of the equator.

Hybrid Rocket
(See Rocket, Hybrid)

Hyperbolic Navigation
(See Navigation, Hypergolic)

Hypergolic (Self-igniting)
A propellant system which is capable of spontaneous ignition on contact.

Hypersonic
(See Sonic, Hyper)

Hysteresis
The lag between the response of a unit or system to an increasing signal and its response to a decreasing signal.

I

I_{sp}
(See Specific Impulse; Specific Impulse, Ideal or Theoretical)

IBDA
(See Indirect Bomb Damage Assessment)

ICAO Atmosphere
(See Atmosphere, ICAO)

ICBM
(See Missile, Intercontinental Ballistic)

ICW
(See Continuous Wave, Interrupted)

IF
(See Frequency, Intermediate)

IFF
(See Identification, Friend or Foe)

IGOR (Intercept Ground Optical Recorders)
A 108'' focal length telescopic camera used for missile test range instrumentation. Usually fitted with a 35 mm or a Mitchell camera. Range coverage up to 100,000 ft.

IOC
(See Initial Operational Capability)

IRBM

(See Missile, Intermediate Range Ballistic)

I^2R Loss

Power loss in transformers, genarators, connecting wires and other parts of a circuit due to current flow I through the resistance R of the copper conductors. Also termed copper loss.

Ice Crystal Clouds

At temperatures below about 15° F water vapor changes to solid water directly without the intermediate liquid-water stage. Cloud particles form directly on sublimation nuclei as ice crystals, and such clouds are then composed of ice-crystal particles. Cirro-form clouds are of the ice-crystal group.

Identification, Friend or Foe (IFF)

A method of automatic identification of an aircraft or ship. A coded challenging transmission received by a correctly adjusted receiver in a friendly vessel causes the automatic transmission of an identification signal, usually on another frequency.

Igniter

A device used to initiate burning of a fuel mixture or a propellant in a ramjet or rocket combustion chamber respectively. A pilot-burner in a ramjet may serve the same purpose.

Ignition System

The system associated with rocket engines which provides for igniting the propellant.

Image Point

With an airburst atomic bomb, a point beneath the surface of the earth, equal in depth to the height of the exploding bomb. (The image point is a source of radiating reflected shock.)

Imitative Deception

(See Deception, Imitative)

Impact Area

(1) The area in which the missile and/ or its payload strikes the surface of the earth. The Intended Impact Area is the target area.

(2) The area along the line of flight where jettisoned parts will strike the surface of the earth after separation from the missile at staging. (e.g., stage-one impact area; booster rocket impact area).

Impact Detector

(See Detector, Impact)

Impact Fuze

(See Fuze, Impact)

Impact Point

A point along the line of flight where jettisoned parts will strike the surface of the earth or sea after stage separation.

Impact Predictor

A scheme or mechanism for continously estimating the coordinates of a missile impact point, usually based on present position and velocity information obtained by optical or electronic tracking. Equations are solved and trajectories and time-to-go are estimated by ground computers. The information may be used by the range safety officer to destroy the missile or for an early assessment of performance to assist in making a decision for firing the next round.

Impedance, Acoustical

The complex quotient of the pressure applied to the system by the resulting volume current. The unit is the acoustical ohm.

Impedance, Electrical

The ratio of the effective value of the potential difference between the terminals to the effective value of the current, there being no source of power in the portion of the circuit under consideration. The unit is the abohm.

Impedance, Matching

Two impedances are matched when they have the same magnitude and the same phase angle; the transmission of power between them is thus maximized. (See Matching Impedance)

Impedance, Mechanical Rectilineal (Mechanical Impedance)

Mechanical rectilineal impedance is the complex quotient of the alternating force applied to the system divided by the resulting linear velocity in the direction of the force at its point of application. The unit is the mechanical ohm.

Impedance, Mechanical Rotational (Rotational Impedance)
Mechanical rotational impedance is the complex quotient of the alternating torque applied to the system divided by the resulting angular velocity in the direction of the torque at its point of application. The unit is the rotational ohm.

Impedance, Source
(See Source Impedance)

Implosion
(See Collapse)

Impulse
In rocketry, the area under a thrust-time curve. For constant thrust, it is equal to the product of thrust and time; units: lb/sec.

Impulse, Air Specific
(See Specific Impulse, Air)

Impulse, Fuel Specific
(See Specific Impulse, Fuel)

Impulse Maneuver
(See Maneuver)

Impulse, Over-All Specific
(See Specific Impulse, Over-All)

Impulse-Reaction Turbine
A turbine which employs the principles of both the impulse and reaction systems. Normally the reaction occurs in increasing effect towards the rotor blade tips, and no reaction occurs at the blade roots.

Impulse, Specific
(See Specific Impulse)

Impulse, Specific - Ideal or Theoretical
(See Specific Impulse, Ideal or Theoretical)

Impulse, Total
In jet propulsion usage, the product of the average thrust (in pounds) developed by the engine, times the burning time (in seconds).

Impulse Turbine
A turbine which imparts energy by the use of a high-velocity, low-pressure gas flow through the rotor blades.

Impulse-Weight Ratio
In rocketry, the ratio of total impulse to takeoff weight.

Independent Components
In reliability studies, those components whose reliability is independent of the remainder of the system: e.g., no functional or environmental interaction.

Indirect Bomb Damage Assessment (IBDA)
The means, usually independent of the guidance system, for confirming the detonation of a nuclear explosion, its position, its position with respect to the target and the resulting damage.

Induced Roll
Missile roll motions resulting from induced rolling moments. (See Induced Rolling Moments)

Induced Rolling Moments
The moment resulting from aerodynamic forces which acts to roll a missile during flight at angles of attack other than zero. It is encountered under conditions of large lateral accelerations, particularly when large angles of attack are used. These induced ments may be attributed to:
(a) Wing tip effects
(b) Wing root effects
(c) Separation effects on body and wing surfaces
(d) Sweepback effects
(e) Downwash effects or interference on the tail surface

In general, anything which effects the symmetry of the missile during a lateral maneuver at large angles of attack is apt to produce rolling moments.

Inductance
(1) That property of an electric circuit or of two neighboring circuits which determines the electromotive force induced in one of the circuits by a change of current in either of them.
(2) Inductance in an electrical system is that coefficient which, when multiplied by 2π times the frequency, gives the positive imaginary part

of the electrical impedance. The unit is the abhenry.

Inductive Feedback

Feedback of energy from the plate circuit of a vacuum tube to the grid circuit through an inductance or by means of inductive coupling.

Inertance

In an acoustical system that coefficient which, when multiplied by 2π times the frequency, gives the positive imaginary part of the acoustical impedance. The unit is the gram per centimeter to the fourth power.

Inert Explosive

An explosive which can withstand severe environmental and handling loads without danger of spontaneous detonation.

Inertia

A measure of the reluctance of a body to change its translational and rotational velocities (including changes from zero). For translational motion inertia and mass are equivalent.

Inertial Activator

(See Activator, Inertial)

Inertial-Gravitational Guidance System

(See Guidance System, Inertial-Gravitational)

Inertial Guidance

(See Guidance, Inertial)

Inertial Guidance System

(See Guidance System, Inertial)

Inertial Navigation System

(See Navigation System, Inertial)

Inertial System

A system which is able to determine the displacement of its carrying vehicle from its starting point by measuring the accelerations of the vehicle relative to the earth.

Infantry Mil

(See Mil)

Influence Coefficients

Constants of proportionality which permit determination of a given parameter at one point when certain related characteristics are known at another point.

Influence Fuze

(See Fuze, Influence)

Influence Line

Usually pertains to a particular section of a beam, and is a curve so drawn that its ordinate at any point represents the value of the reaction, vertical shear, bending moment or deflection produced at the particular section by a unit load applied at the point where the ordinate is measured. An influence line may be used to show the effect of load position on any quantity dependent thereon, such as the stress in a given truss member, the deflection of a truss, the twisting moment in a shaft, etc.

Infrared

A portion of the electromagnetic spectrum in which the wave length is between 0.3×10^{-5} cm and 7.6×10^{-5} cm. It falls between the visible light and the microwave regions of the spectrum.

Infrasonic

Having a frequency below the audible range. Frequencies above the audible range are termed ultrasonic or supersonic.

Inherent Stability

(See Stability, Inherent)

Inhibitor

An inert material surrounding a solid propellant rocket grain to limit burning except on desired surfaces.

Initial Failure

(See Failure Modes)

Initial Operational Capability (IOC)

A term used to describe, comprehensively, the initial adequacy of a weapon system to be used in the field operationally.

Initiation

The application of a fuze signal to the first elements of an explosive train.

Injector

In liquid rocket engines, the device which functions to direct, mix and/or atomize the propellants to provide a proper mixture for combustion. (See Injector, Non-Impinging; Injector, Impinging; Injector, Spray)

Injector, Impinging

A liquid rocket engine injector in which the oxidizer and fuel are mixed

by the intersection of jet-streams at a predetermined point.

Injector, Non-Impinging

A liquid rocket engine injector in which the oxidizer and fuel do not impinge at a specific point but are mixed as a result of the combustion chamber turbulence.

Injector, Spray

A liquid rocket engine injector in which the oxidizer and fuel are mixed by intersection of spray patterns.

Inner Body

Any closed body located in the ram-jet, or other, duct, around which the air taken into the diffuser or engine must flow.

Inner Loop

In guided missile control systems, the feedback loop consisting of the control system and missile aerodynamics as contrasted to the outer loop which includes the external guidance system dynamics. (See Fig. 10.25, p. 451)

Inspection

Examination of an item to determine compliance with established standards and/or specifications.

Inspection, Periodic

An inspection repeated either at regular intervals of calendar time or, in reference to certain equipment, after a thing has been used for a given number of hours.

Inspection, Visual

Inspection by the use of the eyes only; does not include use of any measuring devices, tools, or equipment.

Installation

A separately located and defined area of real property in which an armed service exercises real property interest or has jurisdiction over real property. Real property, as used here, includes lands and interest therein, buildings and structures, utility systems, runways, and installed equipment. Installation is synonymous with Air Force Base, Naval Base, etc.

Installations Concept

A broad over-all statement of the installations operation to be performed. It contains an outline of the objectives, assumptions, criteria, and capabilities needed in the preparation of the installations plan.

Installations Plan

The projected method of obtaining the goals prescribed in the installations concept. The plan is developed from the guidance contained in the concept.

Installed Equipment

Nonexpendable or expendable recoverable equipment permanently attached to or integrated into real property in such a manner that it cannot be removed without causing substantial physical damage or change to the real property.

Instantaneous Sound Pressure

(See Sound (Acoustomotive) Pressure)

Instrumentation

Devices used to gather quantitative data on a guided missile system or its components while these are operating or being tested.

Instrumentation Console

The console, housed in the control building, controls all ground instrumentation equipment, including the central timing system.

Integrating Accelerometer

(See Accelerometer, Integrating)

Integrating Gyroscope

(See HIG (Gyro); Gyroscope, Integrating)

Interceptor Lead-Angle

The angle between the flight path of an interceptor on a collision course with a target and the interconnecting line-of-sight.

(ICBM)

(See Missile, Intercontinental) Ballistic)

Interface

(1) The boundary, electrical and/or mechanical, existing between two systems or components. Characteristics are usually specified by installation, interface, or coordination drawings and coordinated tooling.

(2) The boundary between two media, especially as transited by a propagated wave.

Interference (Electronic)

An electrical or electromagnetic disturbance that causes undesirable responses in electronic equipment. Electrical interference refers specifically to interference caused by the operation of electrical apparatus that is not designed to radiate electromagnetic energy.

Interferometer

An apparatus used to produce and show interference between two or more wave trains coming from the same luminous area, and also to compare wave lengths with observable displacements of reflectors, or other parts, by means of interference fringes. An interferometer is frequently used to obtain quantitative information on flow around bodies in wind tunnels.

Interferometer Homing

(See Homing, Interferometer)

Intergalactic Space

(See Space, Intergalactic)

Interlock

A device used to govern a sequence of operations to prevent injury to personnel or damage to equipment.

Intermediate Range Ballistic Missile (IRBM)

(See Missile, Intermediate Range Ballistic)

Intermittent Jet

(See Pulsejet)

Internal Star-Shaped Grain

(See Star Grain)

Interplanetary Space

(See Space, Interplanetary)

Interrupted Continuous Wave (ICW)

(See Continuous Wave, Interrupted)

Intra-Planetary Space

(See Space, Intra-Planetary)

Interstellar Space

(See Space, Interstellar)

Inverse Feedback

(See Feedback, Inverse)

Inverse Feedback Filter

(See Filter, Inverse Feedback)

Inverse Mercator Projection

In cartography, a special case of the transverse Mercator Projection, being that projection which results if the cylinder on which the earth's surface is projected is placed tangent to the earth at a meridian.

Inversion

(1) A meteorological condition wherein the temperature below the stratosphere normally decreases with altitude. When temperature increases with altitude, normal conditions are inverted, and the condition is said to be an inversion. Inversions in the troposphere are usually restricted to shallow layers of air which most frequently occur in the lower 5000 ft above the surface. In low latitudes the stratosphere has a slight inversion more or less permanently.

(2) In optics, the transformation of an optically-active substance into one having the opposite rotatory effect, without essential change of chemical composition.

(3) In communications, a form of speech-scrambling which essentially inverts the original frequency spectrum of the signal. This may be accomplished by modulating the signal with a relatively low-frequency carrier, and then discarding the carrier and upper sideband.

Ionization

(1) The process of charging neutral atoms or molecules either positively or negatively.

(2) Causing gas to become a conductor of electricity.

Ionosphere

That part of the atmosphere extending from 30 miles to 250 miles altitude. Regions of ionization (approx. maxima):

D	Layer -	35 to 40 miles
E	Layer -	70 to 80 miles
F_1	Layer -	135 to 145 miles
F_2	Layer -	190 to 230 miles

The ionosphere consists of layers of highly ionized air capable of bending or reflecting certain radio waves back to the earth. Ionization results principally from ultraviolet solar radiation. Some

seasonal and day-to-night variation is expected. (See Fig. 10.5, p. 400)

Ion Propulsion

A means of obtaining propulsion for space ships by expelling ions and electrons from a combustion chamber. The recombination aft of the chamber prevents space charge effects which would counteract the thrust.

Isentropic Flow Through A Converging Nozzle

A constant-energy thermodynamic process which is representative of the gas flow in a De Laval nozzle.

Isoclinic Lines

Lines connecting points bearing equal magnetic dip angles. Isoclinic lines are the counterpart of latitude lines in the geographical system and are rightly paralleled to the equator. The line connecting points having a zero vertical component (e.g., zero dip angle) is the magnetic equator.

Isodynamic Lines

Lines having equal magnetic intensity in the horizontal plane.

Isoelastic

Property of a body to experience a strain throughout which is proportional to the stress. This property is important in gimbal-mounted gyroscopes where a missile acceleration may produce distortions and unwanted precessions unless the gimbals and gyroscopes are isoelastic.

Isogonic Lines

Lines connecting points having equal magnetic declination. Isogonic lines are the counterpart of longitudinal lines in the geographical system. The two lines along which the magnetic declination is zero are termed agonic lines.

Isolation Network

A network inserted in a circuit or transmission line to prevent interaction between circuits on each side of the insertion point. Often a tube is used for this purpose.

Isolator Efficiency

In an elastic system, the ratio of the energy absorbed by an isolator at a particular load and deflection (or stress and strain) to the product of the particular load and the deflection (or stress times strain).

Isolator (Shock or Vibration)

Any material or structure which tends to diminish the effect of shock or vibration on any item.

Isotopes

Elements occupying the same place in the periodic system, having the same nuclear charge, but differing somewhat in atomic weight. Most of the ordinary inactive elements have been shown to consist of a mixture of isotopes.

Isotropic Warhead

(See Warhead, Isotropic)

J

Jammer

An electronic device for jamming.

Jammer, Automatic Search

An intercept receiver and jamming transmitting system that automatically searches for and jams enemy signals of specific radiation characteristics.

Jammer, Repeater

A repeater jammer serves to confuse or deceive the enemy by causing his equipment to present false information; this is accomplished by a system that intercepts and reradiates a signal on the frequency of the enemy equipment, the reradiated signal being so modified as to cause the enemy equipment to present erroneous data on azimuth, range, number of targets, etc.

Jamming

A countermeasure technique in which an attempt is made to block a communication or control channel to abort an enemy mission. (See Countermeasure)

Jamming, Accidental

Accidental jamming is jamming due to transmission by friendly equipment.

Jamming, Active

Active jamming is the intentional deliberate radiation or reradiation of electromagnetic energy with the object of impairing the use of a specific band of frequencies.

Jamming, Barrage

Barrage jamming is the simultaneous jamming of a number of adjacent channels or frequencies.

Jamming, Off-Target

Off-target jamming is the employment of a jammer at a point removed

from the main units of the force, this being done to defeat the enemy's use of our jamming signals to his advantage.

Jamming, Passive

Passive jamming is the utilization of confusion reflectors (q.v.) to return spurious and confusing signals to the transmitting radar set.

Jamming, Spot

Spot jamming is the jamming of a specific channel or frequency.

Jato (Jet Assisted Take Off)

An auxiliary rocket device for applying thrust to some structure or apparatus; usually providing a large thrust for a short time for airplane takeoff or missile launching.

Jato Cant Point

The intersection of the jato chamber axis and nozzle centerlines.

Jerk

In kinematics, the third derivative of displacement; rate of change of acceleration. Jerk is useful in defining the nature of shock loads.

Jet Engines

Propulsive devices for guided missiles which impart thrust by the production of a high velocity gas stream. Two general types are of major importance:

(a) Thermal Engines
Ramjet, pulsejet, turbojet (See Ramjet; Pulsejet; Turbojet)

(b) Rocket Engines
Liquid, solid (See Rocket Engine)

Jet Horsepower

The power of the exhaust jet equal to the product of thrust and effective jet velocity. (See Fig. 7.3.1, p. 286)

Jet Propulsion

(See Propulsion, Jet)

Jet Stream

In meteorology, two circumpolar air currents moving in a highly-irregular, periodically-variable, east-to-west direction. Their general location is about 35,000-55,000 ft above the earth's surface, and to middle-to-northern and middle-to-southern latitudes; thus the northern hemisphere jet stream passes over the United States and the Mediterranean, with loops much farther north. The velocity varies from 100 to 500 miles per hour.

Jettison Device

(1) A mechanism for jettisoning a missile from a ship or launcher.

(2) A mechanism for jettisoning a section of a missile in flight. e.g., at staging of a ballistic missile.

Jettison Weight

The weight of equipment and parts dropped at staging of a ballistic missile; the weight of a booster.

Jet Vane Controlled Missile

A missile which is controlled by special vanes placed in the exhaust nozzle of the sustaining rocket or by some special jets acting normal to the missile conterline at a distance from the center of gravity to produce the necessary control moments.

Jet Vane Stabilization

A means of controlling a missile by deflecting vanes in the exhaust stream of a (usually) rocket. Attitude stabilization only may be the objective (e.g., boost phase stabilization) or guidance and/or roll control may be obtained.

Jitter

(See Beam Jitter)

Johnson Noise

The noise generated by any resistor at a temperature above absolute zero. It is proportioned to the absolute temperature and the bandwidth under consideration. Johnson Noise is given by:

$$N = KTB$$

where N = noise power in watts
K = Boltzmann's constant
T = absolute temperature in degrees Kelvin
B = the bandwidth in cycles per second

Jolt and Jumble Tests

Environmental tests used to evaluate equipment for adequacy for handling and shipment.

j-Type (Intrinsic) Semiconductor

In solid state physics, a semiconductor in which the electrical properties are essentially not modified by impurities or imperfections within the crystal.

Junction
In a semiconductor device a region of transition between semiconducting regions of different electrical properties.

Junction, Collector
In a semiconductor device, a junction normally biased in the high-resistance direction, the current through which can be controlled by the introduction of minority carriers.

Junction Transistor
(See Transistor, Junction)

K

K
A solid propellant rocket term; the ratio of propellant surface to nozzle throat area.

K Band
A radio frequency band of 11,000 to 33,000 mc/sec with a corresponding wave length of 2.7 to 0.9 cm.

K-Kill
A standardized term which classifies the damage inflicted upon an aircraft target by a missile. For a K-Kill the aircraft must fall out of control without a reasonable doubt. It is a specialized case of the general A-Kill which applies to all targets. (See Kill)

Katabatic Wind
In meteorology, a cold air drainage downhill toward lower terrain. In desert ravines katabatic winds locally reach high velocities.

Kernel
In mathematics, a function of two sets of variables used to define an integral operator. If the integral operator so defined is the inverse of a differential operator, the kernel is known as the Green's function belonging to the differential operator. (Diffusion kernel or Yukawa kernel: a Green's function of the elementary diffusion equation; slowing-down kernel: the probability that a neutron will go from one position to another while slowing down through a specified energy range.)

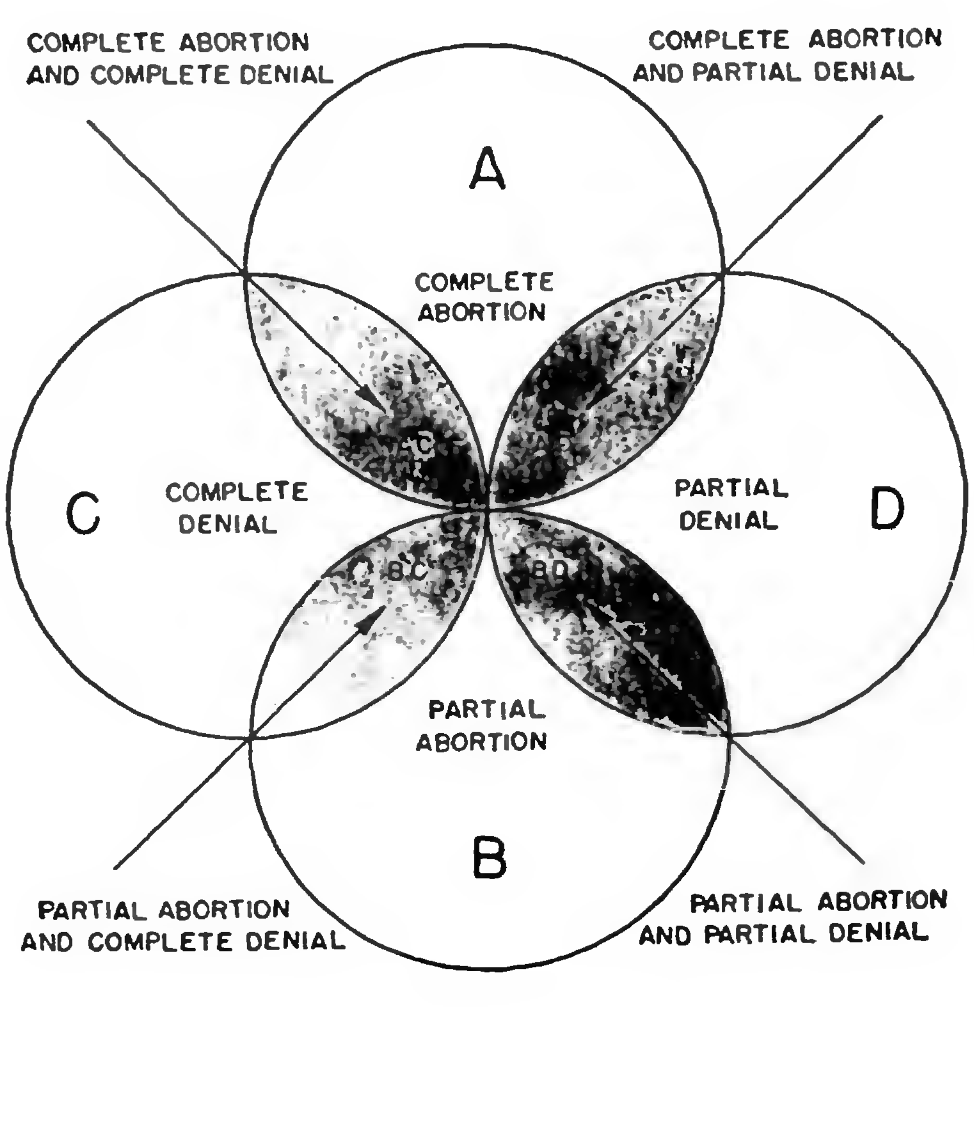
Kill
The achievement of a desired effect against an enemy target.

Symbol	Kill	Definition
A	Complete abortion	The enemy attack is less than 1% effective as compared with an unopposed successful attack.
B	Partial abortion	The enemy's attack is thwarted so that his destructive effect is reduced, but not as much as for complete abortion.
C	Complete denial	The enemy force or resource attacked is completely destroyed or made unavailable to him for use in further war activity.
D	Partial denial	The enemy force or resource attacked cannot be used in further war activity unless repaired or replaced in part, or until after a lapse of time.

(See Abortion; Attrition; K-Kill)
(See Fig. 10.36)

Kill Measure (Rank)
The order of desirability of several kills.

FIG. 10.36 FOUR BASIC TYPES OF KILL AND THEIR COMBINATIONS



Kill Probability

(1) The chance that a target will be destroyed by a given operation.

(2) The likelihood of producing the desired kill under the conditions specified.

(See Fig. 10.3, p. 394)

Kill Probability, Cumulative

If the single-shot probability is p_k, the p_{km} which results (assuming no progressive damage) from firing m shots at the target is:

$$p_{km} = 1 - (1 - p_k)^m$$

(See Fig. 10.37)

Kirchhoff's Current Law

A fundamental electrical law which states that the sum of all the currents flowing to a point in a circuit must be equal to the sum of all the currents flowing away from the point.

Kirchhoff's Voltage Law

A fundamental electrical law which states that the sum of all the voltage sources acting in a complete circuit must be equal to the sum of all the voltage drops in that same circuit.

Klystron

A vacuum tube for converting direct-current energy into radio-frequency energy by alternately slowing down and speeding up an electron beam, utilizing the transit time between two points to produce a velocity-modulated electron stream to deliver radio-frequency power to a cavity resonator. The term is applicable to an ultra-high-frequency amplifier, or generator, that combines the velocity-modulation principle with one or more cavity resonators to produce and/or utilize a velocity-modulated beam of electrons.

L

L

(See Lift)

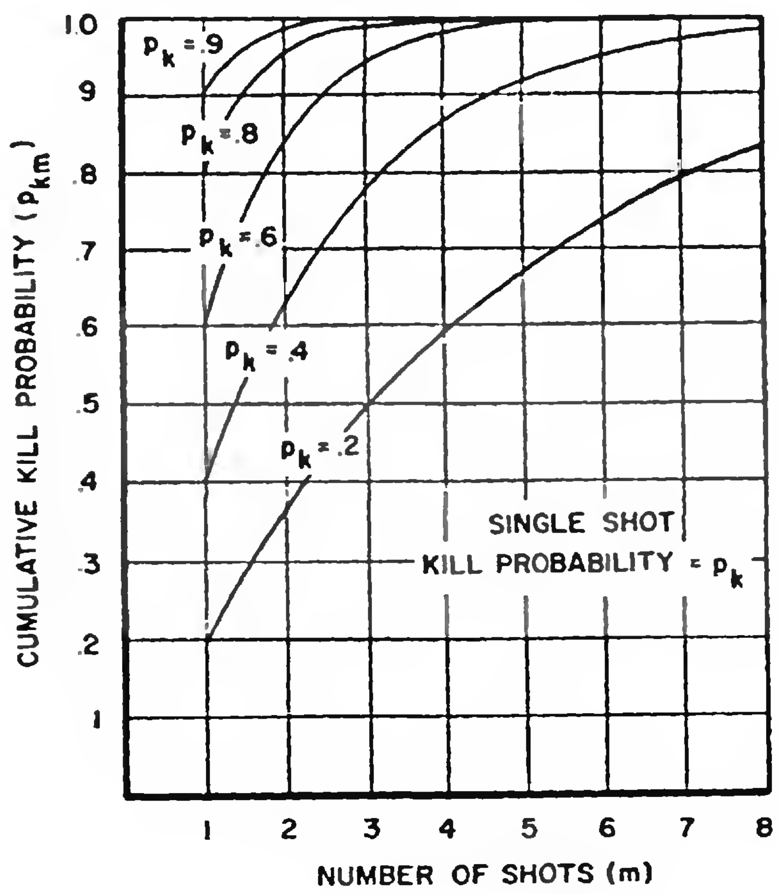
L Band

A radio frequency band of 390 to 1550 mc/sec with corresponding wave lengths of 77 to 19 cm.

LC Product

A term used in circuit design. The inductance L in henries, multiplied by the capacitance C in farads.

FIG. 10.37 CUMULATIVE KILL PROBABILITIES AFTER SEVERAL FIRINGS



LC Ratio

A ratio used in circuit design. The inductance in henries, divided by the capacitance in farads.

LN_2

Liquid nitrogen.

LORAN

(See Navigation, Hyperbolic)

Lambert Conformal Projection

In cartography, a means for portraying the earth's surface. A cone is placed over a sphere representing the earth, with the axes of the cone and of the sphere in coincidence. The size of the cone is such that it cuts the surface of the sphere at the two parallels representing the parallels of latitude which have been selected as the standard parallels of the projection. The meridians of the sphere are projected onto the cone and so determine the the meridians of the chart. The land masses on the sphere are then projected onto the cone. In the Lambert conformal projection the area lying between the standard parallels is compressed and the area lying outside the standard parallels is expanded.

Standard parallels are arcs of concentric circles with the apex of the cone as a center. The area between the standard parallels may be further divided by swinging additional arcs for other parallels of latitude. The meridians are straight lines converging at the apex of the cone.

Advantages of Lambert Conformal Projection:

(a) The distortion is comparatively minor. There is no distortion along the standard parallels.

(b) The same distance scale may be used anywhere on the chart, with negligible error.

(c) Meridians and parallels intersect at right angles and the angles formed by any two lines on the surface of the earth are correctly represented on the chart.

(d) A straight line on the chart closely approximates a great circle. The Lambert conformal projection thus also satisfies the requirements for guidance use.

Laminar Flow

In aerodynamics, the condition wherein the layers of air close to a surface are smooth, although of different velocity with respect to each other.

Lanchester Damper

A mechanical damper used in servos and mechanical systems in which the damping element is a flywheel; the damper depends on the acceleration forces required to rotate the wheel for the damping. The wheel is sometimes submerged in oil to provide additional damping.

Late

A term describing armament which functions after the target has been passed and, therefore, cannot be damaged.

Late Bird

A missile which arrives at the intersection of the missile-target trajectories after the target has passed the intersection and is out of the damage volume of the missile.

Lateral Stability (and Control) Coefficients

(See Stability (and Control) Coefficients; Stability, Lateral)

Latitude

The latitude of any place is its angular distance north or south of the equator and is also the angle at the earth's center subtended by the arc of the meridian contained between the equator and the place. Latitude is measured numerically in degrees north or south of the equator.

Launch Area

(See Launch Base Area)

Launch Base Area

For ground-launched missiles, a geographic area encompassing numerous command posts, launch stations and associated guidance stations, a control center, and a support base.

Launch Complex

The facilities and equipment required for launching a missile including launcher, blockhouse, ground guidance, launcher servicing and other required ancilliary equipment.

Launch Flight

(See Flight)

Launch Pad

A specific facility from which one missile at a time can be launched.

Launcher

A mechanical structure which constrains a missile to move in the desired direction of flight during initial motion but does not itself propel the missile.

Launcher and Missile Storage Structure, Surface or Underground

A single structure combining the functions of the launcher and the missile storage structure.

Launcher, Rail-type

A structure supporting a set of rails which in turn support the missile-jato combination. The rails provide orientation and control during the early portion of the launching phase.

Launcher, Retractable

A launcher designed to carry a missile in one position and extend it to a new position for launching.

Launcher, Underground

(See Underground Launcher)

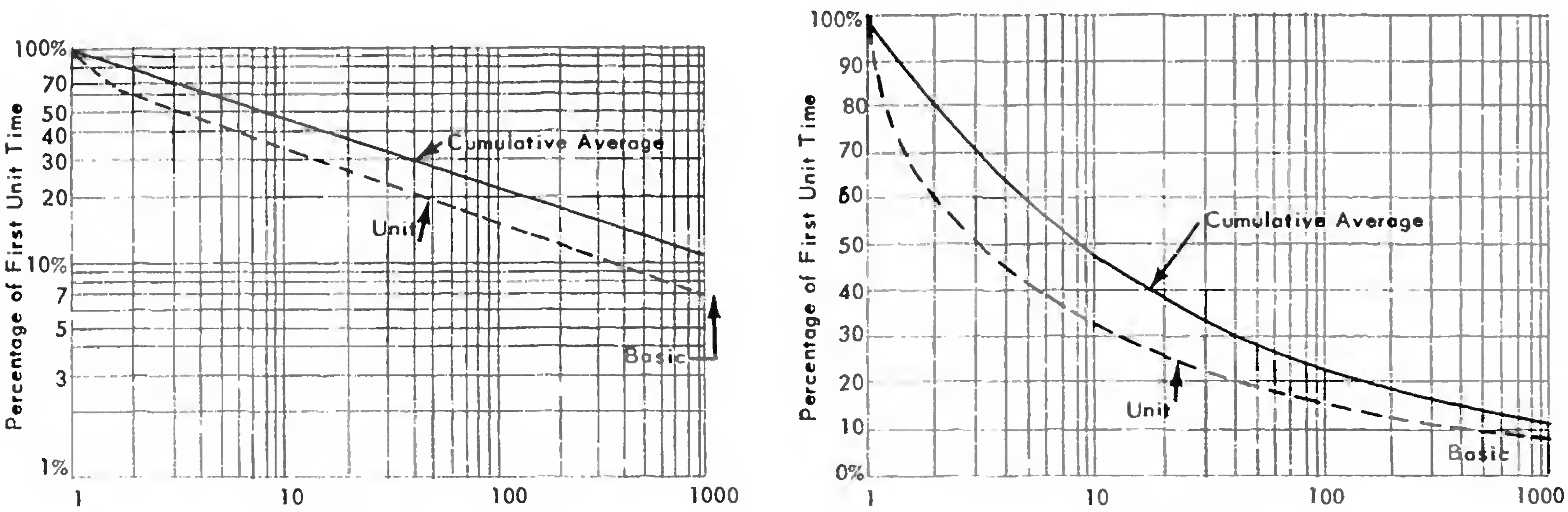
Launcher, Zero Length

A launcher which supports the missile in the desired attitude prior to ignition, but which exercises negligible control on the direction of the missile's travel after ignition.

Launching Dispersion

The departure (usually but not necessarily, random) from the desired flight

FIG. 10.38 LEARNING CURVES



80% learning curve for direct labor as percentage of first unit time (log-log plot)

80% learning curve for direct labor as percentage of first unit time (semilog plot)

path which a guided missile takes during the launching phase.

Launching Ramp

A ramp used for launching an aircraft or missile into the air.

Launching, Retro

(See Retro Launching)

Launching Rocket

(See Booster Rocket; Jato)

Launching Silo

A type of underground launcher.

Launching System, (Naval)

That part of a ship's installation designed and installed for the purpose of providing a means for launching a missile on a desired trajectory at a desired time. It may be either a static type with the missile providing its own ejection power or a catapult type in which the launcher powers or assists the missile take-off.

Launch-Latch

(1) A device which locks the S and A and which is released at missile takeoff.

(2) A device which restrains a missile until the proper conditions for its launching have been achieved.

Launch Site

The location of a Launch Complex.

Lead Control

In servomechanisms, the control of the stability of feedback systems by use of lead networks.

Leading-Edge Pulse Time

(See Pulse Time, Leading-Edge)

Lead Prediction

The act of directing a missile (or projectile) ahead of a moving target, leading in aim, to a predicted collision point.

Learning Curve

A graphic representation of the increase in proficiency of personnel with increase in experience.

(See Fig. 10.38)

Le Chatelier Principle

A general law for physical systems: If a system is subjected to a constraint whereby the equilibrium is modified, a change takes place, if possible, which partially annuls the constraint.

Life Test

A test under controlled conditions and specified environment to determine life expectancy of an equipment. The test is designed to establish the failure probability for a given sample size.

(See Fig. 3.18, p. 96)

Launch Station

One or more launchers with associated storage, assembly, and maintenance facilities.

Launch Station, Augmented

A launch station with facilities for launching two or more missiles.

Lift (L)

In aerodynamics, the force available to overcome gravity and/or maneuver a missile which results from the flow of air over a lifting surface or body. (See Eq. 5.6, p. 214)

Lift Coefficient (C_L)

A dimensionless parameter relating to the lift characteristics of a surface of body. Values may be derived from wind tunnel or full scale flight tests. (See Eq. 5.6, p. 214)

Lift (due to) Drag

(See Drag)

Lift-off

The event of a missile leaving the launcher.

Light Gas Gun (Mass Accelerator)

A test apparatus using light gases instead of powder charges for propulsive energy. Projectiles at speeds starting at 10,000 mph and increasing to 20,000 mph may be obtained.

Limit Cycle (Servo)

An oscillation of a servomechanism in which the maximum amplitude is reached and which continues at (usually) a fixed or varying frequency.

Limiter

In electronics, a circuit which limits the maximum positive or negative values of a wave form to some predetermined amount. (It is used in frequency modulation systems to eliminate unwanted variations of amplitude in received waves.)

Limit Load Factors

In structural design, the maximum actual accelerations (in gravity units) anticipated during the life of the missile. Limit loads are obtained by multiplying the unit (one g) loads on the missile by the limit load factor.

Limit Loads

(See Load, Limit)

Linear

A term describing the dynamic behavior of a system in which the individual block elements which make up the whole system behave linearly over their operating ranges; thus they may be represented by systems of linear equations, e.g., a linear network is an electrical network in which the currents and voltage can be related by a set of linear integro-differential equations with constant coefficients; these coefficients are functions of the parameters of the network.

Linear Accelerator

A motion-producing test device which sets up a field of rapidly moving electromagnetic waves which carries a test projectile along at extreme speeds by induction.

Linear Amplifier

(1) In electronics, a pulse amplifier in which the output pulse height is proportional to an input pulse height for a given pulse shape and up to a point at which the amplifier overloads.

(2) Any amplifier in which the output signal is directly proportional to the input, within specified conditions.

Line-of-Sight Course

(1) A course in which the missile is guided so as to remain on the line joining the target and the point of control.

(2) The distance to the horizon from an elevated point, including the effects of atmospheric refraction. (See Fig. 6.7, p. 241)

Line Squall

In meteorology, an extremely turbulent, roll type, squall cloud usually found at the leading edge of squall lines associated with rapidly moving cold fronts.

Liquid Propellant Rocket Engine

(See Rocket Engine, Liquid Propellant)

Lissajous Figures

A characteristic and useful portrayal of the combination of two sine waves. (See Fig. 9.18, p. 384)

Load, Basic

In stress analysis, the load on a structural member or part of a missile in a condition of static equilibrium. When a specific basic load is meant, the particular condition of equilibrium must be indicated.

Load Cells

Strain gauges incorporated in the thrust mounts to weight the missile, and measure forces acting upon the vertical missile when in the test or launch stand.

Load, Design

In stress analysis, a specified load below which a structural member or part should not fail. It is the probable maximum applied load multiplied by the factor of safety. Also, in many cases, an

appropriate basic load multiplied by a design-load factor.

Load Factor

In stress analysis, the ratio of the force acting on a mass to the weight of the mass. The net external force on the mass may be expressed in terms of gravity units.

Limit Load Factor is the maximum value of gravity units expected during the life of the missile.

Load, Limit

In stress analysis, the maximum values of load expected during the life of the missile. Usually multiplied by one to obtain design load.

Loads Report

A standard report used in structural design which includes the basic transportation, storage, stowage, handling, environmental, launcher, boost, flight and recovery loads; spanwise and chordwise pressure distributions on all important elements; inertia and gust loads for all important flight phases; pressure vessel loads; rotary and longitudinal acceleration factors, etc. Special and conventional design methods and techniques on which the design is based should be included.

Load, Ultimate

In stress analysis, the maximum load a structure will support without failure. (The ratio of ultimate and limit loads is the factor of safety.)

Load, Working

In stress analysis, the load at which a structure works. Usually, but not always, the Design Load.

Lobe

One of the three-dimensional portions of the radiation pattern of a directional antenna.

Lobe, Side

A portion of the radiation from an antenna outside the main beam and usually of much smaller intensity. A side lobe is a region between two minima in the pattern.

Local Oscillator (For Microwave Radar Receivers)

(1) An electronic device for generation of a reference frequency. It may be of the usual low-frequency, negative-grid type with the tuning circuits consisting of coaxial elements; or, more often, velocity modulation tubes are used. (The latter type is practically the only suitable oscillator for receiver use above 4000 mc per sec).

(2) The oscillator in a superheterodyne receiver which supplies the frequency to the mixer necessary to heterodyne the original signal frequency down to the desired intermediate frequency. The elements for this oscillator may be in the same tube envelope as the mixer.

Lockon

The instant at which a radar is enabled automatically to track its target.

Lockon Range

The range from a radar to its target at lockon.

Logarithmic Amplifier

In electronics, an amplifier whose output signal is a logarithmic function of the input signal.

Logarithmic Decrement

The natural logarithm of the ratio of two successive amplitudes of a decaying system. Useful in determining the amount of damping in a system by measuring the rate of decay of oscillation.

The logarithmic decrement

$$\delta = \log \frac{X_1}{X_2} = \gamma \omega_n \tau$$

where $\gamma = \dfrac{c}{c_c}$ = damping factor

$$\omega_n = \sqrt{\frac{k}{m}} = \frac{c_c}{2m}$$

(See Eq. 4.21, p. 183)

Logical Design

A computer design discipline in which the computational features and elements are logically grouped to provide an entity capable of handling a piece of data or to make a particular calculation.

Logistics

The functions of supply and transport in support of the military establishment; i.e., those aspects of military operations that deal with:

(a) design and development, acquisition, storage, movement, distribution,

maintenance, evacuation and disposition of materiel;
(b) movement, evacuation and hospitalization of personnel;
(c) acquisition or construction, maintenance, operation, and disposition of facilities; and
(d) acquisition or furnishing of services. It comprises both planning (including determination of requirements) and implementation.

Logistics Concept
A general statement of approved military policy on logistics for a specified weapon system. The logistics concept establishes the overall logistics policies, objectives, assumptions and requirements for the particular weapon system, based upon the weapon system requirements presented in the operations concept.

Logistics Plan
The logistic plan is based on the operations plan, and guidance contained in the logistics concept. It includes a general description of the materiel support system and specific guidance to the using commands and subordinate command activities on actions to be taken and methods of supporting the weapon system.

Longeron
In structural design, an element used to carry drag or compressive loads; also used to "break up" sheet panels to provide increased rigidity and load carrying capacity. Typical use: semi-monococque construction of missile airframes.

Longitude
The angle between a place of interest and the earth's prime meridian through Greenwich, England; measured numerically in degrees east or west of the prime meridian.

Longitudinal Stability
(See Stability, Longitudinal)

Loop
A loop is a series of interconnected components, accessories, assemblies or subassemblies required to complete a specific function such as tracking, temperature control, antenna positioning, synchronizing, pressure control, etc., within a system.

Low-Order Detonation
(See Detonation)

Lox
Liquid oxygen (See Fig. 7.8.4, p. 300, for properties)

Loxing Time
The time needed to pump the required amount of liquid oxygen into the missile lox tank or tanks and to reach a state of launch readiness.

Loxodromic Curve
In cartography, a rhumb line which spirals toward the poles.

Lumped Constant Elements
Distinct electrical equipments, small compared to a wavelength, which are calibrated and used in the control of voltage and current, and employed in conjunction with other electrical-electronic equipment.

Lunar Space
(See Space, Lunar)

M

mae
(See Mean Absolute Error)

MAL
Materiel Allowance List

MEAL
(See Master Equipment Allowance List)

meru (milli-earth rate unit)
0.001 revolution of the earth per day.

MHE
Materiels Handling Equipment

MIL STD
(See Military Standard Specification)

MIRAN
(See MIssile RANging)

MOC
Master Operational Controller.

MS
(See Margin of Safety)

mtbf
(See Mean-Time Between Failure)

MTI
(See Moving Target Indicator)

Mach Angle
The angle between a Mach line and the path of a body moving with supersonic speed. The sine of this angle is the ratio of the local speed of sound to the missile velocity.

Mach Cone

A hypothetical conical surface having at its apex a point source moving with supersonic speed, all of the shock disturbances remain inside the surface. Outside of the Mach cone the fluid is unaffected by the motion of the moving body. The Mach cone is bounded by a weak shock wave and a line drawn on the Mach cone from the vertex is known as a Mach line.

Mach Diamond

A series of spaced, light areas in rocket exhausts caused by local equilibrium shifts.

Mach Line

An imaginary line drawn at an angle to the path of a rapidly moving body. It represents theoretically the shock wave which would be produced by a microscopic point moving with the speed of the body. The angles of very weak shock waves closely approximate the angle of the Mach line.

Mach Meter

An instrument for sensing the Mach number of a missile in flight. (This parameter is often used to adjust the gain of the control system or engine thrust).

Mach Number

A fundamental aerodynamic parameter; the ratio of the velocity of a body to that of sound in the medium being considered. Thus, at sea level, in air at the Standard Atmosphere, a body moving at a Mach number of one (M=1) would have a velocity of approximately 1116.2 ft/sec or 688 knots. (See Fig. 2.13, p. 44 and Eq. 7.1.7, p. 276)

Mach Wave

In supersonic aerodynamics, the limiting case of an infinitely weak shock wave.

Magic Tee

In microwave techniques, a particular radar wave-guide configuration, so-called because its physical aspect resembles a double letter "T". The use of this configuration permits the coupling of a radar transmitter and receiver to a common antenna without the use of a T-R (Transmit-Receive) unit.

Magnaflux Testing

A method of inspection used to locate cracks, cavities or seams in steel parts at or very close to the surface. Special equipment has been developed for this test and several methods are used. In principle, the part is magnetized and magnetic powder is applied, wet or dry. Flaws that are not otherwise visible will be indicated by the powder clinging to them. Because of many variables that may be present in this test, considerable experience is needed for uniform interpretation of results.

Magnetic Equator

(See Isoclinic Lines)

Magnetic Inclination

(See Dip)

Magnetic Tape

(1) A means for storing information by varying the magnetic properties of a moving tape.
(2) Tape impregnated with a ferromagnetic substance which undergoes varying magnetization corresponding to the magnitude of an applied alternating current.

Magnetic Testing

A nondestructive means for testing ferromagnetic materials to determine variations in the physical and chemical properties, stress concentrations, structures, etc. In general, the tests are used to determine defects such as cracks, seams, voids or inclusions, and consist of passing an electric current (AC or DC) through the part to create a magnetic field about the part, or through a coil surrounding the part to create a magnetic reaction within the part. Discontinuities in structure are flux leakage points and are easily located by use of appropriate instruments or equipment.

Magnetic Wire

Wire capable of storing information by undergoing changes in magnetization conforming to the applied current representing the desired information.

Magnetometer

A device for measuring the earth's magnetic field, notably magnetic anomalies.

Magnetron

A high-vacuum thermionic tube capable of producing high output power in the microwave region of the frequency spectrum. The tube consists of a heater, cathode,

usually a multisegment anode, and an external magnet (electro or permanent) for controlling the unidirectional current flow in the tube.

Magnification Factor

Given a flexibly supported object undergoing forced vibration, the magnification factor is a measure of the response of the object to the vibration and is the ratio between the magnitude of a particular characteristic of the vibration of the object and the same characteristic of the forcing vibration. Characteristics of particular concern are: acceleration, displacement, and force; but displacement is usually meant unless otherwise indicated.

Main Stage

The phase is liquid rocket engine operation during which full thrust is developed.

Maintenance Depot

A military base where maintenance is performed on materiel requiring major overhaul or a complete rebuilding of parts, sub-assemblies, assemblies, and end items. It performs the manufacture of parts, modifications, testing and reclamation as required.

Maintenance, Engineering

The logistic function of devising and developing maintenance systems, procedures, practices, techniques, and policies.

Maintenance, Field Level

That maintenance authorized for, the responsibility of, and performed by designated maintenance activities in direct support of using organizations. This category of maintenance normally includes intermediate and major inspection of equipment; the repair of unserviceable parts, assemblies, subassemblies and components; the local manufacture of nonavailable parts; testing, calibration, and reclamation as authorized.

Maintenance, Organizational

That maintenance authorized for, the responsibility of, and performed by a using organization on its assigned equipment. Organizational maintenance will normally consist of pre-flight, post-flight and periodic inspection of missiles, daily or minor inspection of other materiel, servicing, preventive maintenance, calibration of systems, and removal and replacement of components.

Maneuver

In space flight, a controlled change of orbit usually by means of thrust force (impulse maneuver), but possibly also by by utilizing a perturbation force (perturbation maneuver).

Maneuverability

The ability of a missile to alter its flight path to meet tactical requirements; specifically that structural or aerodynamic quality in a missile or aircraft which determines the magnitude and rate at which its attitude and direction of flight can be changed. Commonly expressed in "g's".

Maneuver, Capture

In space flight, change from an open (parabolic or hyperbolic) orbit to a closed orbit near a celestial body.

Maneuver, Correction

In space flight, change of orbit for the purpose of obtaining closer agreement with a pre-calculated orbit.

Maneuver, Escape

In space flight, change from a closed orbit to an open orbit near a celestial body.

Maneuver, Impulse

(See Maneuver)

Maneuver, Perturbation

(See Maneuver)

Manipulative Deception

(See Deception, Manipulative)

Man-year

An effort equal to that of one person for one year. (It is equivalent to 2080 man-hours that must be paid for. The somewhat lesser number of effective man-hours obtained from one man-year will depend upon local conditions and the type of personnel involved. The normal number of effective man-hours per man-year is approximately 1768.)

Map Matching

A guidance method in which a terrestrial reference is used. An airborne map obtained from reconnaisance is compared with actual terrain for guidance information.

Margin of Safety (MS)
As used in missile design, the percentage by which the ultimate strength of a member exceeds the design load. The design load is the applied load, or maximum probable load, multiplied by a specific factor of safety. The use of the terms margin of safety and design load in the above sense is practically restricted to aeronautical engineering. (See Eq. 4.29, p. 187)

Marginal Testing
A procedure for system checking which indicates when some portion of the system has deteriorated to the point where there is a high probability of a resultant system failure during the next operating period.

Marker Flare
A pyrotechnic device employed in a missile in flight tests to mark an event of significance; the light or smoke emitted is photographically recorded.

Marriage
The process of physically uniting the missile stages and all major subsystems.

Masking
The condition where a part of the missile structure blocks a portion of the warhead emission, fuze sensing area, or electromagnetic radiation area.

Mass
(1) Mass in engineering units is the weight of a body divided by the acceleration of gravity. The unit is the slug.
(2) Mass in a mechanical oscillatory system is that coefficient which when multiplied by 2π times the frequency, gives the positive imaginary part of the mechanical rectilineal impedance. The unit is the gram.

Mass Accelerator
(See Light Gas Gun)

Mass Ratio
(1) The ratio of the initial mass of a rocket to the mass after final burnout. (λ) (always greater than unity)
(2) The ratio of the mass of a rocket after fuel burnout to the initial mass.
Note that these commonly used definitions are reciprocals! (Fig. 8.1, p. 312)

Master Equipment Allowance List (MEAL)
A publication that prescribes allowances of organizational equipment to be authorized to Technical Operation units through the medium of the unit mission equipment column of the Unit Authorization List.

Master Operational Controller (MOC)
The central control and monitoring point for all launch station activities necessary for preflight checkout, countdown sequencing, firing, and postfiring deactivation.

Matching, Impedance
The technique of minimizing the standing-wave ratio when two devices having unlike impedances are coupled together. This process, at the same time, maximizes power flow between the two devices, assuming one to be a source and the other a sink. (See Impedance, Matching)

Material - Guaranteed Minimums
Physical properties of materials which are expected by the producer to be minimum and therefore are guaranteed. Tensile ultimate and yield are usually the only guaranteed values--all others being on a derived basis.

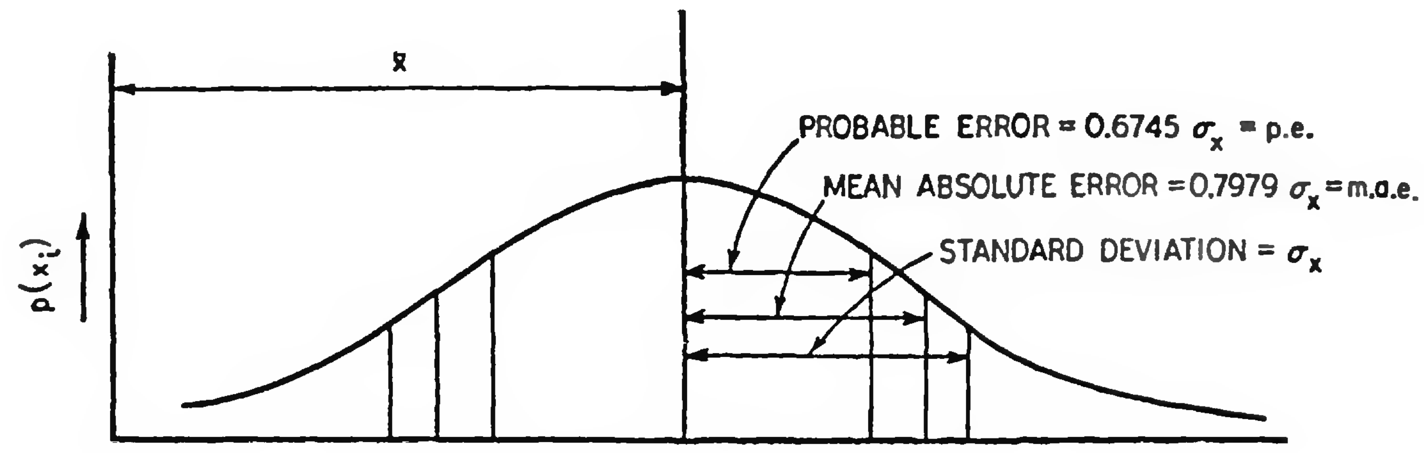
Material - 90% Probability Values
Physical properties of materials which are expected to be obtained or exceeded by 90% of the material delivered by the producer. These are statistical values based on facts for tensile ultimate and yield; other properties are derived.

Materiel
All items necessary for the equipment, maintenance, operation, and support of military activities without distinction as to their application for administrative or combat purposes.

Materiel Control
That phase of military logistics which embraces the act of managing, regulating, and directing the production, procurement, and distribution of materiel necessary to meet operating requirements.

Mathematical Logic
(See Symbolic Logic)

FIG. 10.39 ILLUSTRATING NORMAL DISTRIBUTION AND RELATION OF PROBABLE ERROR, MEAN ABSOLUTE ERROR, AND STANDARD ERROR



Maximum Ordinate

The distance from the center of the earth to the apogee of the missile trajectory or, alternatively, this distance minus the radius of the earth.

Maximum Sound Pressure

(See Sound (Acoustomotive) Pressure)

Meaconing

A system for receiving electromagnetic signals and rebroadcasting them with the same frequency so as, for instance, to confuse navigation. A confusion reflector, such as chaff, is an example. (See Jamming; Countermeasures)

Mean Absolute Error (mae)

In measurement theory, the arithmetic mean of all errors without regard to sign. Also termed the average error.

$$\text{mae} = \frac{\Sigma|X_i - \bar{X}|}{n}$$

(See Fig. 10.39)

Mean Error

In measurement theory, the mean value of an error as contrasted to the spread of errors about that mean value. Also termed arithmetic mean, algebraic average, and bias.

Mean Free Path

The distance the average molecule in a gas will travel before striking another molecule. At sea level conditions the mean free path of a molecule is a very small fraction of an inch. As altitude increases, the atmospheric density drops because there are less molecules in a given volume of air. The criterion for continuity is the mean free path of a molecule.

Mean Life

The arithmetical mean (average) of the operating time between failures.

Mean-Time Between Failure (mtbf or m)

Of a complex system (in which failed parts are replaced with new parts of equal failure rate) is essentially the average time between outages caused by catastrophic failures. It can be determined by dividing the product of the number of equipment tested (N) and the test time (t) by the number of failures (f) which occur during that time, i.e., mtbf or often just $m = \frac{Nt}{f}$.

"m" is the reciprocal of λ, i.e., $m = \frac{1}{\lambda}$

and is related to the probability of survival by the exponential failure law

$P_s = e^{-\frac{t}{m}}$. The figure of merit "m" is convenient for use in determining if the reliability of an equipment is likely to be adequate for missions of specific lengths. "m" is sometimes expressed as $\bar{t}$.

Mechanical Compliance

(See Compliance; Compliance, Mechanical)

Mechanical Filter

(1) A filter, which is usually sharply tuned, consisting of appropriately-shaped metal rods which act as a series of coupled mechanical resonators. Electrical coupling into and out of the filter may be accomplished by piezoelectric transducors. Since successful operation of these filters may be achieved up to several hundred kilocycles, the filters find frequent application in the intermediate-frequency amplifiers of "very selective" superheterodyne receivers.

(2) Any mechanical device used as a band pass filter.

Mechanical Injuries

Injuries caused by flying debris or fragments.

Mechanical Pilot

(See Automatic Pilot)

Mechanical Properties

Those properties that reveal the reaction, elastic and inelastic, of a material to an applied force, or that involve the relationship between stress and strain; e.g., Young's modulus, tensile strength, fatigue limits. These properties have often been designated as physical properties, but the term mechanical properties is much to be preferred.

Mechanical Rectilineal System

A mechanical rectilineal system is a system adapted for the transmission of linear vibrations consisting of one or all of the following mechanical rectilineal elements: mechanical rectilineal resistance, mass and compliance.

Mechanical Rotational System

A mechanical rotational system is a system adapted for the transmission of rotational vibrations consisting of one or all of the following mechanical rotational elements: mechanical rotation resistance, moment of inertia and rotational compliance.

Mechanical System

An aggregate of matter which possesses mass and whose parts are capable of relative motion.

Memory Unit

In computer usage, a memory device in which data required for computation is stored until needed.

Mercator Projection

In cartography, a means for portraying the earth's surface. To obtain the proper proportion, the meridians are expanded in the same ratio as the parallels. As the latitude increases, the parallels expand on an increasing scale, and accordingly the meridians expand in proportion. To compensate for this error, different scales must be used on Mercator charts for measuring distances in different latitudes. The expansion of the latitude and longitude scales approximates the secant of the latitude for short distances.

Meridian

Great circles of the earth which pass through its poles. The prime meridian is the meridian used as the origin of measurement of longitude. The meridian of the original site of the Royal Observatory at Greenwich, England is used by nearly all of the countries in the world as the prime meridian.

Mesopause

That altitude (about 50 miles) at which the temperature profile changes. It separates the mesosphere and the thermosphere in the Chapman atmosphere.

Mesosphere

That portion of the atmosphere extending from about 250 miles to 650 miles altitude (Gerson); or, from 15 miles to 50 miles altitude (Chapman temperature nomenclature).

Metal Parts

A generic term inclusively describing the parts of a solid propellant rocket excepting the propellant charge, the inhibitor (inert liner) and the igniter. (Metal parts may comprise between 10 and 40% of the gross weight of a rocket.) (See Fig. 10.52)

Metal Parts/Weight Ratio

A term used in solid rocket design to ratio the weight of the metal parts to the total weight of the loaded rocket excluding special fittings and attachments. It equals unity minus the propellant/weight ratio.

Meteor

A transient celestial body that enters the earth's atmosphere with great velocity, incandescent with heat generated by the resistance of the air.

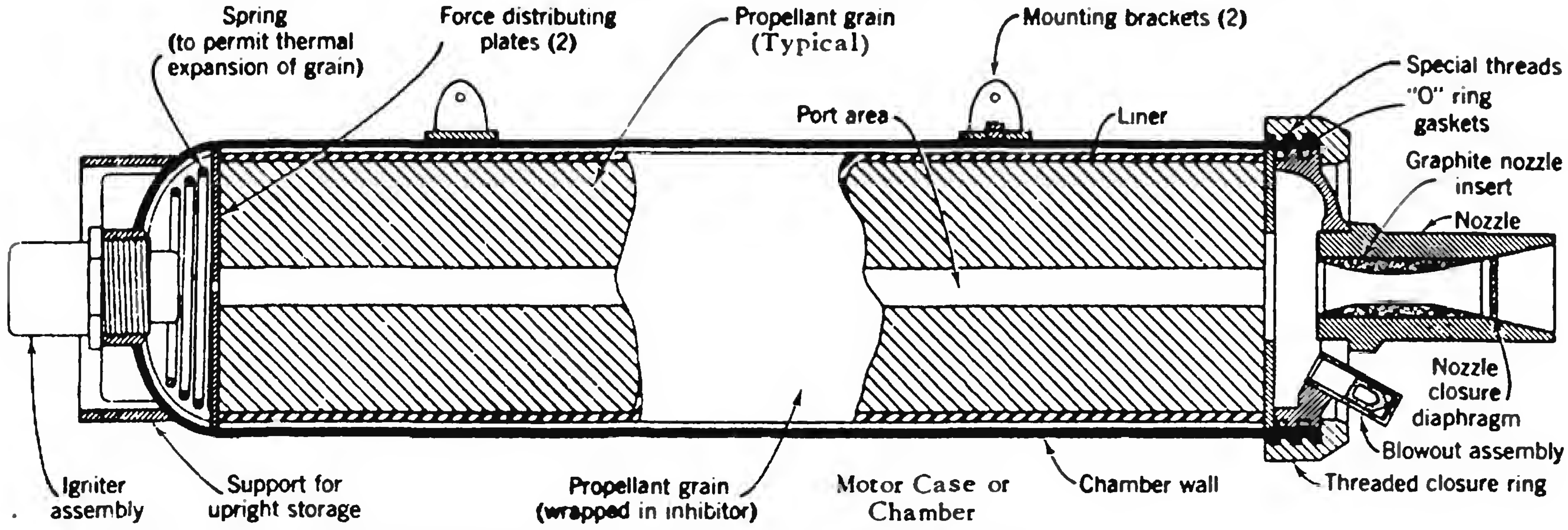
Meteorite

A stony or metallic body that has fallen to the earth from outer space.

Microlock

A phase lock-loop system for transmitting and receiving information. It may be used as a radar beacon for tracking, or to provide telemetering data. The system reduces bandwidth drastically.

FIG. 10.52 SECTIONAL VIEW OF TYPICAL SOLID PROPELLANT ROCKET



From Sutton, G. P., "Rocket Propulsion Elements," Copyright 1956, Wiley, New York.

Microminiaturization

Reduction of equipment size by orders of magnitude over sub-miniature techniques; the combining, merging, or blending of the circuit elements and the device itself.

Microstrip

In electronics, a miniaturized transmission line technique used in the kilomegacycle range. It consists of a wire above a ground plane and is analogous to a two-wire line.

Microwave

A subclassification of the electromagnetic spectrum. Generally covers the wave length regime from VHF to EHF (3 meters to 0.3 cm). (See Fig. 6.5, p. 239)

Midcourse

That phase of a guidance trajectory usually initiated at the end of the boost or launching phase and ending at the start of the terminal or homing phase.

Mil

(1) A unit of angular measurement. In artillery and guided missile usage, a mil is equal to 1/6400 of a circle. In infantry usage, a mil is the angle subtended by 1 yard at 1000 yards distance. 100 artillery mils equals 98.2 infantry mils.

(2) A unit of linear measurement equal to 0.001 inch.

Milestone

An activity or action within the research, development, test, production, and in-service life of a project. The milestone possesses a distinct, objectively identifiable, terminal point, which can be used as a means of evaluating the progress of research and development in terms of its estimated schedule.

Military Characteristics

The performance requirements which must be satisfied by an overall system intended to satisfy a military mission.

Military Standard Specification (MIL STD)

A formal specification, coordinated and approved by the Army, Navy, and/or Air Force as appropriate. One of the services usually has cognizance of the specification.

Millisadic

A data processing system used to translate pulse width or analog data into digital form.

Miner's Fuse

(See Bickford Fuse)

Miniaturization

Usually, the reduction in size, weight, or both, of a system, package, component or element by using very small parts and interconnections. Sometime, the addition of a capability, increased power, better performance, etc. for the same size or weight. (See Subminiaturization)

Minor Cycle

In a digital computer using serial transmission, the time required for the transmission of one word, including the space between words.

Minitrack

An electronic interferometer measuring system which gives angular measurement by comparing phase of a signal received at two antennas on a short base line.

Misfire

An unsuccessful attempt to start a rocket motor; usually, but not always, a case where the igniter functions

properly but where the propellant does not ignite (or does ignite but goes out).

Miss Distance

(1) The closest distance between two objects having relative motion: e.g., a guided missile intercepting a target.
(2) The great-circle distance between the observed impact point and the intended impact point.

Missile, Air-to-Air (AAM)

A guided missile which can be launched from one aircraft against another. Passive or active guidance may be used. Usually named for birds: e.g., Falcon, Sparrow. (See Missile, Guided; Model Designation)

Missile, Air-to-Ground (AGM)

A guided missile with or without a propulsion system which can be launched from an aircraft against a surface target. Categories include air-to-ground and air-to-underwater types. (See Missile, Guided; Model Designation)

Missile, Air-to-Surface (ASM)

(See Missile, Air-to-Ground; Missile Guided; Model Designation)

Missile Attitude

The position of a guided missile as determined by the inclination of its axes (roll, pitch, and yaw) in relation to another object, as to the earth.

Missile, Ballistic

Any missile guided especially in the upward part of its trajectory, but becoming free-falling in the latter stages of its flight through the atmosphere.

Missile, Fleet Ballistic (FBM)

(See FBM (Fleet Ballistic Missile)

Missile, Ground-to-Air (Surface-to-Air)

A missile launched from the surface (ground or ship) for the purpose of intercepting an airborne vehicle (e.g., airplane, missile). (Generally used for anti-aircraft defense and may be of a short or long range type).
Usually named from mythological terms (e.g., Nike, Talos)

Missile, Ground-to-Ground (Surface-to-Surface)

A missile launched from the surface (land or sea) against surface targets. Two further categories are used. They depend on (a) whether the missile is to be used for long-range type of offense (e.g., Matador, Snark, ICBM, IRBM, Regulus, etc.), or (b) whether it is of the much shorter-range type used for support of ground troops (e.g., Dart, Corporal, Sargent, etc.)

Missile, Guided

An unmanned vehicle moving above the earth's surface, whose trajectory or flight path is capable of being altered by a mechanism within the vehicle. One classification system in current use:

Surface-to-Surface - missiles may be launched from ground stations or ships against ground installations, surface vehicles, or surface ships. (See Missile, Ground-to-Ground)

Surface-to-Air - missiles may be launched against airborne aircraft, airships, or guided missiles. (See Missile, Ground-to-Air)

Similar variations of the other classifications exist; however, the words surface and air are governing. (See Model Designation)

Missile, Guided Ballistic

A ballistic missile which is guided during the powered portion of the trajectory and utilizes a free ballistic path during a portion of its flight.

Missile - Intercontinental Ballistic Missile - (ICBM)

A missile flying a ballistic trajectory after guided powered flight, usually at velocities in excess of 20,000 fps and capable of operating over ranges in excess of 3500 nautical miles.

Missile - Intermediate Range Ballistic Missile - (IRBM)

A generic term defining a missile flying a ballistic trajectory after guided powered flight and capable of a range of 800 to 2,000 nautical miles.

Missile Lead-Angle

The angle between the flight path of a missile on a collision course with a target and the interconnecting line-of-sight.

Missile, Operational

(See Operational Missile)

MIssile RANging (MIRAN)

A multi-station measuring system

using radar triangulation techniques for measurement of range.

Missile Retainer
(See Tail Grab)

Missile Roll Range
The angle through which the missile can be controlled in roll. It determines the azimuth range of the targets that can be attacked without rotating the launcher.

Missile Servicing Tower
A superstructure providing personnel platforms for missile fueling and servicing.

Missile Storage Structure
The structure and facilities necessary to receive, support, store and service one or more missiles.

Missile Stowage Supports (Naval)
Supports provided within the missile magazine to secure the missile radially at the hard points and prevent excessive sway while being transported at sea.

Missile, Strategic
(See Model Designation; Strategic Missile)

Missile, Sub
(See Sub-Missile)

Missile, Surface-to-Air
(See Missile, Ground-to-Air; Missile, Guided; Model Designation)

Missile, Surface-to-Surface
(See Missile, Ground-to-Ground; Missile, Guided; Model Designation)

Missile, Surface-to-Underwater
(See Missile, Ground-to-Ground; Model Designation)

Missile, Underwater-to-Air
(See Missile, Ground-to-Air; Model Designation)

Missile, Underwater-to-Surface
(See Missile, Ground-to-Ground; Model Designation)

Missile System, Guided
(1) The guided missile itself including all airborne systems (Preferred).
(2) A combination of a guided missile and its ancillary launching, external guidance, test and handling equipment which together accomplish a mission. e.g., destruction of a target.
(See Weapon System)

Mission
The end objective of a military operation; the objective may be tactical or strategic.

Mitchell Camera
A high speed motion picture camera for recording rapidly occurring events during a missile flight test, particularly at launch and impact.

Mixture Ratio
The ratio of the weight of oxidizer used per unit of time to the weight of fuel used per unit of time in bipropellant rocket systems.

Mobile Stations
A missile launch complex designed for mobile use in forward combat areas for defense against aircraft or for attack on enemy targets.

Mobility Analogy
An acoustical-mechanical dynamical analogy in which velocity corresponds to a voltage and force corresponds to a current. (See Mechanical Rectilinear Impedance)

Mock-Up
A mock-up is defined as a structure or device which simulates an actual equipment or element of the missile system, thus enabling investigation of space-relationship, physical fit, and human operations problems. It may also be used for training.

Mode, PI
In a magnetron, the mode of resonance oscillation in which the phase difference between any two adjacent anode segments is π radians.

$$\pi \text{ mode} = \frac{N}{2}$$

where N is the number of cavities

Mode, TE
Any mode of microwave propagation in a wave guide or between parallel plates, in which the electric field is wholly transverse to the direction of propagation. The $TE_{1,0}$ mode is commonly used in rectangular wave-guide transmission lines.

Mode, TEM
A mode of microwave propagation between parallel plates (or in a coaxial transmission line), in which the electric

field is everywhere perpendicular to the conductors and the wave length is independent of the spacing between them.

Mode, $TEM_{0,1}$

A mode of microwave propagation which has axial symmetry if excited in a circular wave guide.

Model Atmosphere

(See Atmosphere, Model)

Model Designation

A formal designation for a missile assigned by the government. One system, among others, in current use:

AAM Air-to-Air Missile
ASM Air-to-Surface Missile
AUM Air-to-Underwater Missile
GAM Guided Aircraft Missile
SAM Surface-to-Air Missile
SM Surface-to-Surface Missile
SSM Surface-to-Underwater Missile
UAM Underwater-to-Air Missile
USM Underwater-to-Surface Missile

Preceded by X for Development Missiles
Preceded by Y for Service Test Missiles

Followed by -N for Navy Missiles
-A for Air Force Missiles
-G for Army Missiles

Followed by -odd numbers for Navy Missiles
-even numbers for Air Force Missiles

(See Missile, Guided) (See Fig. 1.1, p. 2)

Model Specifications

A formal specification defining the characteristics of a particualr missile, system or subsystem model. The specification may be an equipment rather than performance type but will include design and test criteria. Usually prepared by the contractor as a contractual requirement.

Moderator

A substance, such as graphite or heavy water, used in a reactor to slow down neutrons from the high energies at which they are released in fission to lower energies at which they cause fission more readily.

Modification

A major or minor change in the design of an adopted item or materiel which is effected in order to correct a deficiency, facilitate production, increase reliability or performance, or to improve operational effectiveness.

Modulation, Amplitude

A method of modulating a radio-frequency carrier by causing the amplitude of the carrier to vary above and below its quiescent value in accordance with the audio or other signal to be transmitted. The frequency of the carrier remains constant. Commonly abbreviated as AM.

Modulation, Frequency

A method of modulating a radio-frequency carrier by causing the frequency of this carrier to vary above and below the quiescent value, at a rate determined by the audio or other modulating signal to be transmitted. The amplitude of the carrier remains constant. Commonly abbreviated as FM.

Modulation, Phase

A method of modulating a carrier-frequency current by causing the phase of the modulated signal (with respect to the unmodulated carrier) to vary from instant to instant in accordance with the audio frequency or other modulation signal. As in frequency modulation, the power output of the transmitter is constant at all times.

Modulation, Pulse

A method of modulating an RF carrier by pulsing it periodically by one or more pulses. Abbreviated as PM.

Modulation, Pulse Duration

(See Telemetering, Pulse Duration Modulation)

Modulation, Pulse Position

A form of pulse time modulation in which the instantaneous sample of a modulating wave controls the time position of a pulse in relation to the timing of a recurring reference pulse.

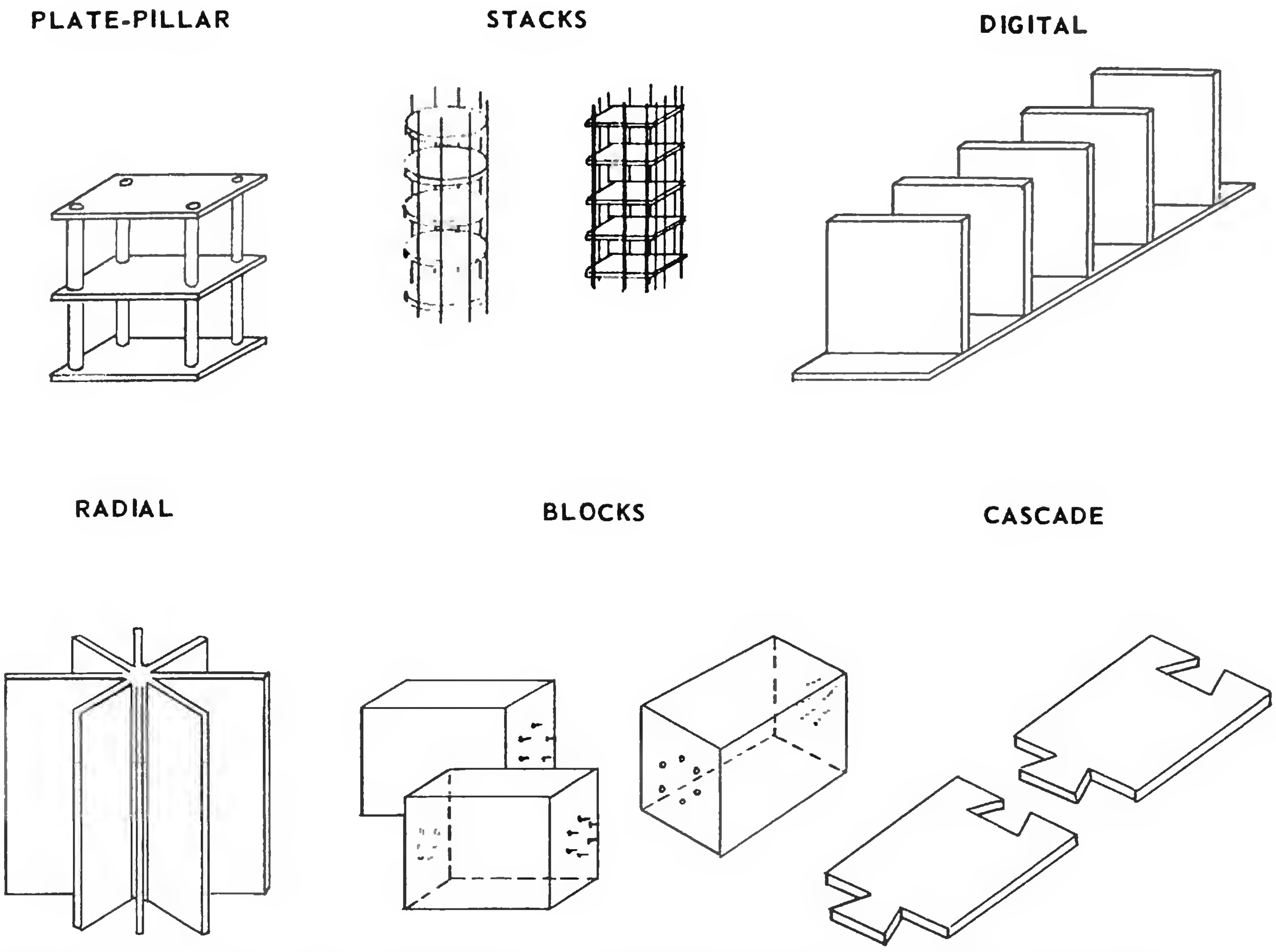
Modulation, Pulse Time

A method of modulating an RF carrier by pulsing it periodically with a reference pulse followed by timed pulses to convey information. Abbreviated as PTM.

Modulation, Pulse Width

(See Telemetering, Pulse Width Modulation)

FIG. 10.40 TYPICAL MODULAR FORM FACTORS



Components and parts are surface or volume mounted. The modules are replaceable as a unit. Form selected is a function of application, space available, heat dissipation required and environment.

Modulator, Double-Balanced
(See Ring Modulator)

Module
(1) As used in the automation and electronics field, a single assembly of parts and/or components to form a larger component which meets a functional requirement by performing all of the resistive, inductive and capacitive functions of a vacuum tube circuit.
(2) A combination of components within a package, or so arranged that they are common to one mounting, that provide a complete function or functions necessary for sub-system or system operation.
(See Fig. 10.40)

Modulus of Elasticity
The ratio, within the limit of elasticity, of the stress to the corresponding strain. The stress in pounds per square inch is divided by the elongation in fractions of an inch for each inch of the original gauge length of the specimen.

Modulus of Resilience
(See Resilience, Modulus of)

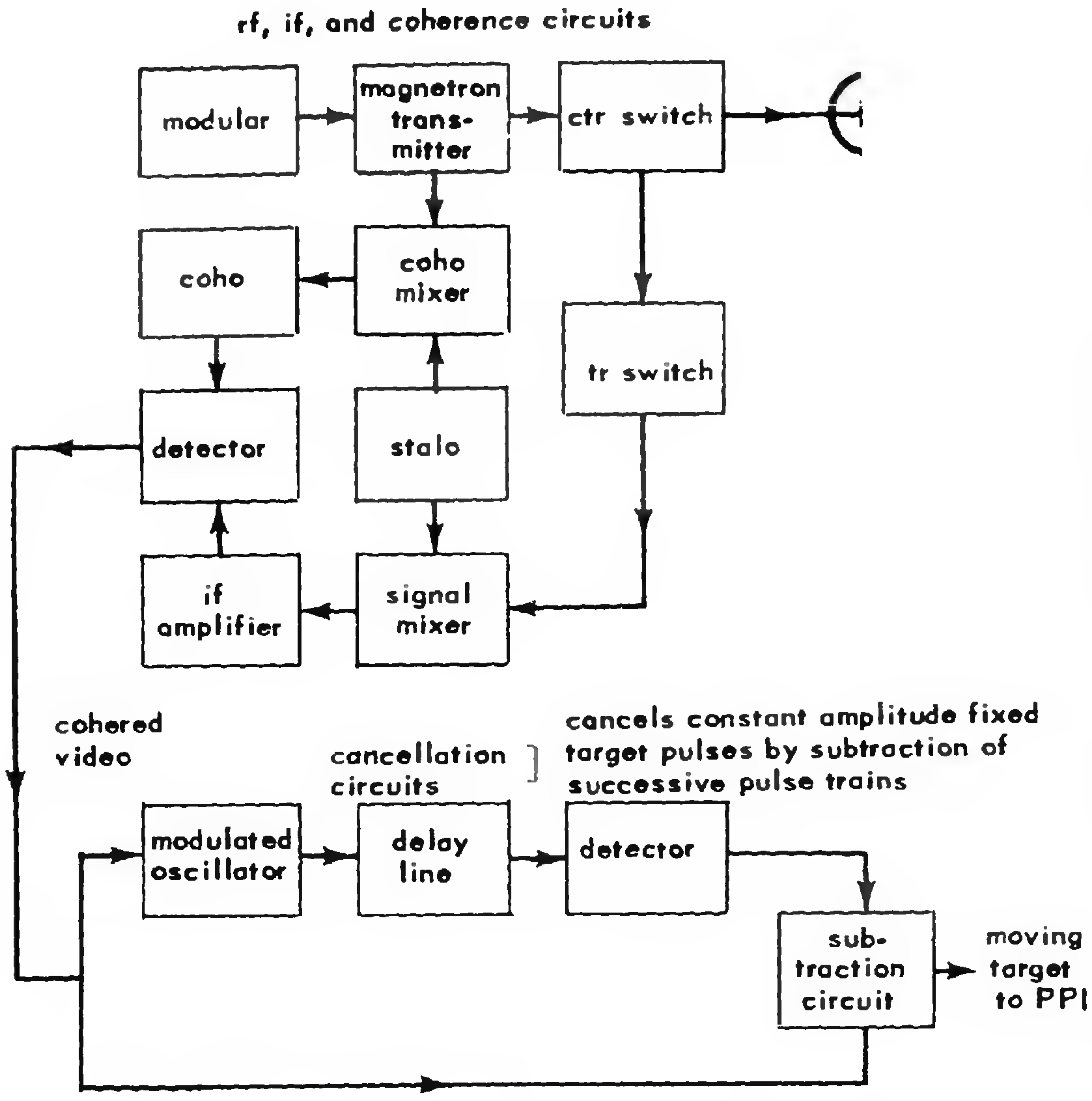
Molecular Beam Tunnel
Used in the study of super-aerodynamics. It operates at extremely low pressures-down to one ten-millionth of a sea level atmosphere.

Moment of Inertia
A measure of the reluctance of a body to change its velocity of rotation about a given axis. The moment of inertia of a body is the product of its mass, acting at a point (often the center of gravity) times the square of the distance of that point from the axis of rotation. (See pp. 166, 184)

Monocoque
A type of airframe construction without framing relying primarily for its rigidity upon the surface or skin which may be of sheet metal or of layers of veneer; a shell-like structure.

Monocoque, Semi
(See Semi-Monocoque)

FIG. 10.41 MOVING TARGET INDICATOR (MTI) RADAR



From Reintjes and Coate, "Principles of Radar," Copyright 1952, McGraw-Hill Book Co., Inc.

Monogole

A monopropellant.

Monopropellant

A rocket propellant which does not require an oxidizer and which decomposes to furnish its own oxidant and reductant.

Monopulse Radar

(See Radar, Monopulse)

Monroe Effect

Reinforcement of explosive waves by each other to produce a stronger resultant wave. The concept is used in the design of shaped charges.

Monte-Carlo Method

A method of solution of a group of physical problems by means of a series of statistical experiments which are performed by applying mathematical operations to random numbers. This method applies most directly to stochastic problems.

Motor Case

(See Motor Chamber)

Motor Chamber

In solid propellant rocket usage, the pressure container or bottle containing the propellant grain to which is attached the nozzle. (See Fig. 10.52, p. 479)

Motor (Rocket)

A generic term for a solid propellant rocket consisting of the assembled propellant, case, ignition system, nozzle and appurtenances. (See Fig. 10.52, p. 479)

Mount

(1) A fabricated shock or vibration isolator, usually consisting of an elastic member and one or more relatively inelastic members, fastened between the equipment to be isolated and its supporting container or structure.

(2) The support for a piece of equipment.

Moving Target Indicator (MTI)

A radar presentation which shows only targets which are in motion, thus improving their contrast to ground clutter. Signals from stationary targets are subtracted out of the return signal by the output of a suitable memory circuit. (See Doppler Radar) (See Fig. 10.41)

m-Type Semiconductor

In solid state physics, an extrinsic semiconductor in which the conduction-electron density exceeds the hole density.

Multiple Grain

An assembly of solid propellant tubular grains inside a rocket motor case; only exterior surfaces of the individual grains are burning surfaces. Total burning surface decreases as the combustion proceeds; the thrust versus duration curve is regressive. (See Fig. 10.16, p. 423)

Multiple-perforated Single Cylindrical Grain

A solid propellant grain with several perforations parallel to its longitudinal axis, all of the burning surfaces are approximately the same distance apart. (See Fig. 10.16, p. 423)

Multiple Shock Intake

In air-breathing engines, a means of increasing the total pressure recovery of a diffuser by reducing the losses encountered with a single normal shock. (See Fig. 10.15, p. 419 and 7.2.3, p. 284)

Multiplexer

A device by which simultaneous transmission of two or more signals may be made using a common carrier wave.

Multiplexing ("Time Sharing" or Commutation)

Denotes the simultaneous transmission of several functions over one link without loss of detail of each function, such as amplitude, frequency, phase, or wave shape. Very high-speed commutation that would satisfy these conditions could, in special instances, be correctly classified as multiplexing. However, to prevent confusion, the term "commutation" is still preferred whenever a switch is used.

Multiplier-Phototube

(See Electron-Multiplier Phototube)

Multistage Rocket

(See Rocket, Multistage)

Mutual Conductance

(See Transconductance)

Mutual Inductance

The flux linkage between two coils due to one unit of current in the other.

N

NPSH

(See Net Positive Suction Head)

NR

(See Noise Ratio)

NSS

National Stockpile Site

Nadir

A point on the celestial sphere 180 degrees from the zenith, i.e., directly beneath the observer.

Natural Frequency

(See Frequency, Natural)

Nautical Mile

A unit of length equalling 6076.103 ft, which is practically the length of a minute of arc of a great circle on the surface of the earth.

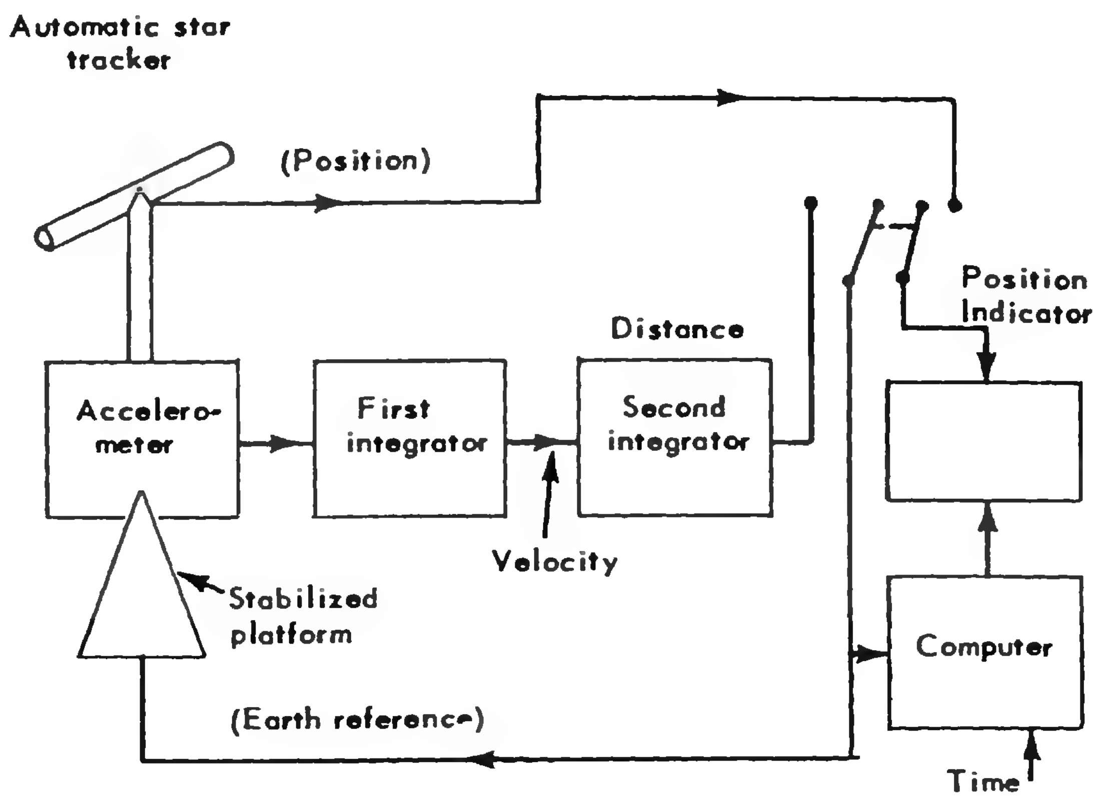
Navigation, Automatic Celestial

(See Star Tracking; Navigation, Celestial)

Navigation, Celestial

Navigation by means of observations of celestial bodies. A system wherein a missile, suitably instrumented and containing all necessary guidance equipment, may follow a predetermined course in space with reference primarily to the relative positions of the missile and certain preselected celestial

FIG. 10.42 FUNCTIONAL SCHEMATIC CELESTIAL NAVIGATION SYSTEM



bodies. Determination of the local vertical to the earth's surface is requisite. (See Fig. 10.42)

Navigation, Constant-Bearing

That missile trajectory wherein it maneuvers so that the seeker is looking at the target in a direction that is fixed in space.

Navigation, Decca

(See Navigation, Hyperbolic)

Navigation, Hyperbolic

A general method for determining lines of position by measuring the difference in distance of the navigator or navigating apparatus from two or more stations of known position. The difference in distance is determined by measuring the difference in time of arrival of signals transmitted from two or more stations. Although a great variety of signaling methods is theoretically possible, only radio waves are now commonly used in hyperbolic navigation. One system, using continuous wave signals, is known as DECCA. LORAN and GEE are systems using signals transmitted as pulses. One transmitting station is the master station, with the other stations or station, separated from 75 miles to 1200 miles, being slave stations. The cycle of transmission always begins at the master station which transmits the signal in all directions. The arrival of the master signal at the slave station "triggers off" the slave which, in turn, transmits a signal. Points of constant

difference in time of arrival of the two or more signals will fall on hyperbolas, with the transmitters at the foci. The accuracy of the line of position which can be established by the navigator or the navigating apparatus varies from 200 yd to 2 miles depending upon the distance and orientation of the observer or the receiver from the base line between stations and upon the type of system and equipment used. Although the navigator's equipment differs in details for GEE, DECCA, and LORAN; the fundamental characteristics are all the same. In the DECCA and GEE systems, the master station operates in conjunction with two or more slave stations. In the LORAN system, the master station operates with one slave station. SHORAN is a short-range system.

Systems now in use:

LORAN, GEE, CYTAC, SHORAN and LORAC use pulsed radio energy; DECCA uses CW radio energy.

Navigation, Proportional

A homing guidance technique in which the missile turn rate is directly proportional to the turn rate in space of the line-of-sight; the seeker tracks the target semi-independently from the missile maneuvers.

Navigation System, Inertial

A system which is functionally the same as inertial guidance except as to end use. It is essentially a form of dead-reckoning device. This means that the geographic position (latitude and longitude or equivalent) of both the starting point and destination must be known and must be set into the equipment.

An inertial navigation system usually requires two or three accelerometers to sense aircraft/missile motion in the north-south direction, east-west direction, and in some applications, in the vertical direction.

Near Miss

The strike of an explosive missile, especially of an aerial bomb, near but not on the object of attack, and usually close enough to it to cause effective damage.

Negative Feedback

(See Feedback, Negative)

Net Positive Suction Head (NPSH)

A parameter used in liquid rocket engine turbopump design to describe the effective inlet pressure conditions to the propellant pumps. The pressure head available at the pump suction flange is provided by tank pressure head, elevation and acceleration forces (and is reduced by line friction and vapor pressure). NPSH is the head available to prevent pump cavitation.

Neutral Burning

A solid propellant rocket term denoting a burning conditions which yields a constant pressure-time curve. (See Fig. 10.16, p. 423)

Neutron Cross Section

A measure of the ability of a material to interact with neutrons by scattering, capturing, or being fissioned by them.

Neutron Flux

A term used to express the intensity of neutron radiation, usually used in connection with the operation of a reactor.

Neutrons

Electrically neutral particles of atomic nuclei with approximately the mass of a hydrogen atom. Neutron radiation is highly penetrating. Free neutrons are often classified according to their speed or temperature, as thermal, slow, intermediate, and fast. This elementary nuclear particle has a mass of 1.00894 AMU. It is possible under certain conditions of excitation, for a neutron to break up into a proton and a beta particle. The neutron, however, is not merely a combination of a proton and electron; it is a distinct entity.

Neutron Source

Any material that emits neutrons, e.g., a mixture of radium and beryllium. A neutron source may be introduced into a nuclear reactor as part of the start-up procedure. The use of neutron source is a safety measure to insure having at the outset a neutron flux large enough to be distinguished from background and measured quickly.

Otherwise, as control rods are withdrawn, the reactor might reach a critical condition before its flux has risen high enough for the control system to operate. Especially if the reactor had become prompt-critical, a rapid and uncontrolled increase in power to a harmful level then might result. When such a source is used, the control instruments show at an earlier stage the approach to critical conditions as safety and control rods are withdrawn. Also used in critical experiments.

Newton's Laws of Motion

(1) Every body continues in its state of rest or of uniform motion in a straight line except in so far as it may be compelled to change that state by the action of some outside force.

(2) Change of motion is proportional to force applied and takes place in the direction of the line of the force.

(3) To every action there is always an equal and opposite reaction.

NIT

In information theory, the choice among equiprobable events. (= 1.44 bits).

Nodal Point

That point on a vibrating body having zero amplitude. The position of the nodal point varies depending on the particular frequency of the vibrating beam. (See Node)

Node

In a vibrating system, a particle which has zero amplitude by virtue of its position in the system.

Node, Partial

In a vibrating system, a particle which has a lesser amplitude than any nearby particles.

Noise

(1) Any unwanted disturbance within a dynamic electrical or mechanical system, such as undesired electromagnetic radiation in any transmission channel or device.

(2) Uncontrolled random disturbances which arise in a guided missile system as a result of various physical phenomena.

Noise Bandwidth

In a dynamic electrical system or servomechanism the frequency at which the open-loop gain equals unity defines the bandwidth effective in reducing system tracking error. It is frequently referred to as the noise bandwidth since below this frequency there is a system gain and above there is attenuation. This frequency is used in determining phase margin. In some instances the asymptotic gain characteristic may, without great error, be used in this connection in place of the actual gain characteristic.

Noise Figure

The degradation of output signal-to-noise ratio. (See Fig. 6.13, p. 246)

Noise, Random (or Fluctuation)

Noises characterized by a large number of overlapping transient disturbances occurring at random.

Noise Ratio (NR)

The ratio of the available noise power available at the output of a transducer divided by the noise power at the input.

Nolo Flight

The flight of a drone without a human (safety) pilot aboard.

Nominal Bomb

A bomb whose energy release is equivalent to that of 20,000 tons of TNT, referred to as a 20 KT (Kiloton) bomb. (Such a bomb was used against Hiroshima in World War II.)

Non-Cooperative Systems (Instrumentation)

Instrumentation systems characterized by transmission of data from the airborne missile equipment to a ground station where the data are recorded: (e.g., telemetry, photo-theodolites).

Nonisoelastic (Anisoelastic) Effects

A source of drift in gyroscopes caused by mass unbalance and nonlinearities resulting from a lack of isoelasticity in materials.

Non-Rotating Earth

A mathematical artifice used in computing performance characteristics of long range ballistic missiles. The trajectory equations are simplified be-

cause of omission of the effects of Coriolis acceleration, earth oblateness, and gravitational anomalies.

Normal Distribution (Gaussian)

The distribution of random variables - found frequently in nature. The principal characteristics of the Normal law are:

(a) It is symmetrical. Negative and positive deviations of equal magnitude are equally likely to occur.

(b) It is a continuous function rather than a discrete function. It assigns a definite probability to every finite deviation. There are no excluded cases.

(c) There is just one most probable result, and this is identical with the first expectation of the variable. (See Fig.10.39, p. 477 and Fig. 3.23, p. 100)

Normal Modes of Vibration

(See Coupled Modes)

Nose Cone

(1) A generic term for the separable payload portion of a long range ballistic missile The Nose Cone includes the warhead, fuzing system, stabilization system, heat shield and supporting structure and equipment.

(2) The payload of a research test vehicle.

Notch Filter

(1) Any band-rejection filter which produces a sharp "notch" in the transfer characteristic of a system.

(2) A filter employed in a television transmitter to provide attenuation at the low-frequency edge of the channel to prevent possible interference with the sound channel of the lower adjacent channel.

Nozzle Cant Angle

The angle which the nozzle axis makes with the jato centerline at the jato cant point.

Nozzle, Canted

(See Canted Nozzle)

Nozzle-Overexpanded

A nozzle in which the working fluid is expanded to a lower pressure than the external pressure (i.e., exit area is too large).

Nozzle, Subsonic

A nozzle in which the velocity of gas at the throat is less than the velocity of sound. The velocity of gas at the exit is also subsonic.

Nozzle, Supersonic

A nozzle in which the velocity of gas at the throat is equal to the velocity of sound. The velocity of gas at the exit is supersonic.

Nozzle-Underexpanded

A nozzle in which the working fluid is discharged at a pressure greater than the external pressure (i.e., the exit area is too small and expansion continues outside the nozzle.

Nuclear Fission

(See Fission, Nuclear)

Nuclear Fusion

A type of nuclear transformation characterized by the combination of two light nuclei, such as tritium, as a result of tremendous pressures and heat. The transformation produces energy and a heavy nucleus.

Nuclear Radiation

Any or all of the radiations emitted as a result of a nuclear transformation. The radiations include gamma radiation (of electromagnetic character) and particle radiations (alpha particles, positive and negative beta particles, and neutrons).

Nuclear Reactor (Commonly only reactor)

(See Reactor, Nuclear)

Nuclear Rocket Engine

(See Rocket Engine)

Nucleonics

The science dealing with protons or neutrons in the nucleus of the atom; or, with all phenomena associated with the atom nucleus.

Nucleus

The positively charged core of an atom that contains the major portion of its mass and the total positive electric charge. Its diameter is about 1/10,000 of the diameter of the atom; including its orbiting electrons.

Null

Zero, or without action; or, in the case of an instrument, without giving a reading.

Nutation

A term describing a particular motion.

(1) In the case of a spinning top or gyroscope, the inclination of the top's axis to the vertical will vary periodically between certain limiting angles. This motion is called nutation. In general a spinning top or gyroscope experiences both nutation and precession.

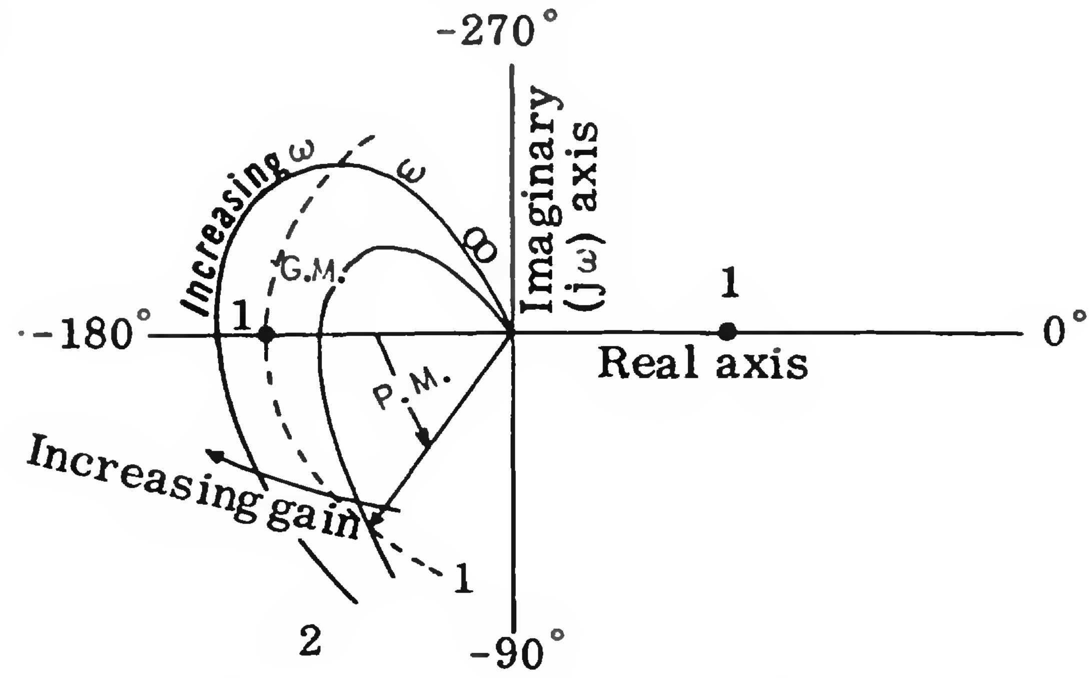
(2) The oscillation of the spin axis of a two-axis gyro initiated by displacement of the base or frame (airframe). It continues with a definite frequency until the disturbance is dissipated and is least pronounced when the gimbals are at 90°.

(3) The orbiting motion (usually wobbling) of a vertex feed at the focus of a paraboloid radar antenna to provide a steady plane of polarization.

Nyquist Criterion

A useful parameter in servomechanism theory; it is the open-loop harmonic response function Y_o $(j\omega)$, and is based upon the properties of functions of a complex variable. A technique used for analysing operating characteristics of closed loop control systems. (See Fig. 10.43)

FIG. 10.43 NYQUIST PLOTS



Typical Nyquist plots of an open-loop transfer function, KG, useful in determining the relative stability of a closed-loop system. Because the system is third-order (at high frequency), the curves asymptotically approach the minus 270 deg axis as the magnitude falls to zero. Curve 1 represents a stable system - it does not enclose the 1 $\angle$ -180 deg point. Curve 2 shows instability - it encloses the point. Phase margin (PM) and gain margin (GM) show relative stability - both are positive. However, when gain increases, they become negative and the system is unstable.

O

O_3

(See Ozone)

OC Curve

(See Operating Characteristic Curve for Acceptance of Sampling Plans)

OJT

On-the-Job Training. A training program that is usually given by a supervisor in the actual performance of work operations.

OpDevFor

(See Operational Development Forces)

ORD

Operational Ready Date.

OSS

Operational Storage Site.

OST

(See Operational Suitability Testing)

Octave

An octave is the interval between two frequencies having a ratio of two to one.

The interval, in octaves, between any two frequencies is the logarithm to the base two (3.322 times the logarithm to the base 10) of the frequency ratio.

Octave Filter

(See Filter, Octave)

Offset Yield Strength

The yield strength of a material determined by the departure of the actual stress-strain diagram from the initial straight line relation of stress and strain (E). (Frequently taken as 0.001 in. per in.)

Off-target Jamming

(See Jamming, Off-target)

Ogive

A body of revolution whose contour is the arc of a circle.

An ogive whose center of arc is in the plane of the base of the nose (thereby creating no break in the contour when attached to a cylinder at its base, that is,

the surface joins the cylindrical surface on the tangent) is defined as a tangent ogive.

An ogive generated by an arc not tangent, but intersecting at a small angle a segment which forms the cylindrical surface is a secant ogive. It may have any radius of curvature greater than that of the tangent ogive on up to an infinite radius of curvature (i.e., a straight, conical ogive) but, unless otherwise specified, a secant ogive has approximately twice the radius of curvature of a tangent ogive.

An ogive generated by a line segment plus an arc of infinite radius is a conical ogive (i.e., a cone plus a cylinder).

Omnidirectional Antenna (or Beacon)

(See Antenna, Omnidirectional)

One and a Half Stage Missile

A ballistic missile which stages part of the booster system but retains the basic tankage and other equipment. The main feature is that the sustainer engine is started on the ground (in contrast to a two stage missile).

One-Line Layouts

Preliminary drawings or sketches depicting structural arrangements and locations in simple form.

Open Loop

A control system in which there is no self-correcting action for departure from the target value, as there is in a closed loop system. (See Fig. 10.44)

Open Loop Testing

A test technique characterized by lack of a feedback path. (See Go-No-Go Testing)

Open Orbit

(See Orbit, Open)

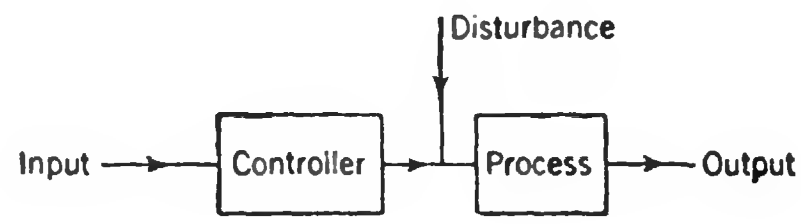
Operating Characteristic Curve for Acceptance Sampling Plan (OC Curve)

A curve showing the relation between the probability of acceptance and either lot quality or process average quality, whichever is applicable.

Operational

A status of evolution of a system or weapon which permits its use by field forces for tactical or strategic applications. Generally, operational missiles

FIG. 10.44 BASIC ELEMENTS OF AN OPEN-LOOP SYSTEM



are supplied from follow-on production to the development missiles.

Operational Capability

The extent to which a system or weapon can fulfill its assigned operational mission.

Operational Concept

A general over-all statement of approved military policy pertaining to a specified weapon system and containing the guidance necessary for the preparation of the logistics, installations, and personnel concepts and the operations plan for that weapon system. The operational concept contains such information as a general description of the weapon system and its application, the organizational structure, the operational capabilities and the utilization of the system, the communications and electronics associated with the system, and the theater and time deployment for the system.

Operational Development Forces (OpDevFor)

A Naval force responsible for tactical evaluation of missiles, weapon systems, and other Naval Ordnance, under fleet operating conditions.

Operational Missile

A missile that, in contrast to a research and development missile, can be used to attack an enemy target.

Operational Readiness

Probability that a system will perform satisfactorily at any point in calendar time. (Same as Up-Time.)

Operational Research

(See Research, Operations)

Operational Requirements

(See Requirements, Operational)

Operational Suitability

A term descriptive of a weapon system which is capable of implementing an operations plan.

Operational Suitability Testing (OST)
Operational suitability testing is performed by the Air Proving Ground Command (APGC) and is conducted under actual or simulated combat and climatic conditions in co-ordination with the using activities.

Operational Suitability Test Facility (OSTF)
An Air Force designation for a site used to test suitability of a weapon system for operational use.

Operations Analysis
(See Research, Operations)

Operations Evaluation
(See Research, Operations)

Operations (or Operational) Plan
An over-all statement of approved military policy pertaining to a specified weapon system and containing methods for achieving the goals of the operations concept.

Operations Research
(See Research, Operations)

Optimization (Optimilization)
The approach to economically perfect design or operation, accomplished primarily by analytical rather than "hit or miss" methods.

Optimum Height of Burst
The calculated height of burst above the earth's surface, or above a target, at which an atomic weapon should be detonated in order to produce a particular effect over the greatest possible area.

Orbit
A line described by a cyclic motion about a center of attraction.

Orbit, Circumplanetary
Orbit (not necessarily closed) about the earth's moon or a moon in general.

Orbit, Circumsolar
Orbit of an artificial asteroid about the sun, of the same kind as a planetary or natural asteroidal orbit.

Orbit, Closed
A circle or ellipse in a central force field (invariant elements).

Orbit, Comet
Orbit with an initial, but not a final, restraint, such as used by instrumental comets.

Orbit, Conic
Orbit in a central force field (orbital elements are invariant).

Orbit, Disturbed
Orbit in a non-homogeneous gravitational field. Such an orbit is not a truly closed orbit (its elements vary).

Orbit, Open
Circle or ellipse in a perturbed field (with changing elements).

Orbit, Satellite
Closed orbit about a celestial body as the center of attraction.

Orbit, Transfer
Line of motion characterized by initial and final constraints.

Orbital Velocity
(See Velocity, Orbital)

Organ, End (obsolescent)
An end instrument, pickup, transducer; a device for measuring a quantity for transmission by a telemetering system.

Organ Pipe Resonance
A resonant organ note produced in a jet engine diffuser-tail pipe under certain conditions of gas flow. It is often accompanied by overheating and therefore to be avoided.

Organizational Maintenance
(See Maintenance, Organizational)

Orthogonal
The property of being at right angles, or, more generally, independent. e.g., the X, Y, and Z directions, or the R, phi and theta directions in polar coordinates are orthogonal. Functions represented by the electric intensities of two radio signals, the ratio of whose frequencies is irrational, are orthogonal.

Oscillation
A periodic phenomenon; e.g., in

servomechanisms a periodic change of the controlled variable from one value to another.

Oscillation, Parasitic

An unintended, self-sustaining oscillation at a frequency different from the operating frequency.

Oscillation, Phugoid

A long-period oscillation characteristic of the disturbed longitudinal motion of a missile.

Oscillation, Stable

An oscillation of constant amplitude or frequency.

Oscillation, Steady-State

(See Steady-State Oscillation)

Oscillation, Unstable

An oscillation whose amplitude increases continuously until a catastrophe occurs or stabilizing forces are brought to bear: e.g., in aerodynamics an oscillation which increases continuously until an attitude is reached from which there is no tendency to return towards the original attitude, the motion becoming a steady divergence.

Oscillator

(1) Any mechanical or electrical device designed to set up and maintain oscillations of a frequency determined by its physical constants: e.g., vacuum tubes, sparks, or arc generators.

(2) In a superheterodyne receiver, that stage which generates a radio-frequency signal of the correct frequency to mix with the incoming signal and produce the intermediate-frequency of the receiver.

(3) In a transmitter, the stage that generates the carrier frequency or a frequency equal to some definite multiple of the carrier frequency.

(4) A test instrument that can be set to generate an unmodulated or tone-modulated radio-frequency signal at any frequency needed for aligning or servicing radio receivers and amplifiers.

(5) A test instrument for generating an audio-frequency signal, at any desired frequency for test purposes.

(6) In early radio, a form of generator of radio transmitter.

(7) In the very high and ultra-high frequencies, a generator that is coupled to some form of radiator as a transmitter.

Oscillator, Backward Wave

A local oscillator employing a special vacuum tube in which oscillatory currents are produced by bunching electrons as they flow from cathode to anode. An oscillatory electromagnetic field is used to bunch the electrons. (Used in radar sets, signal generators, countermeasure receivers, etc.)

Oscillator, Beat-Frequency (BFO)

A device from which a single audio frequency is obtained by combining and rectifying two higher frequencies.

Oscillator, Blocking

An electrical circuit used to generate very narrow pulses. Two types are used:

(1) Free running - determines its own repetition rate and thus may be used as a master oscillator;

(2) Driven - used to convert broad trigger pulses into sharp, short pulses (approx. 1 microsecond duration).

Oscillator, Coherent

A reference is provided by which the RF phase difference of successive received pulses can be established. Used in Moving Target Indicators.

Oscillator, Crystal Controlled

An oscillator using a mechanically vibrating piezoelectric crystal with an energy transfer between mechanical vibrations and the electric circuit, used in place of a resonant circuit as a stable frequency source.

Oscillator, Local

(See Local Oscillator)

Oscillator, Push-Pull

(See Push-Pull Oscillator)

Oscillator, Relaxation

(See Relaxation Oscillator)

Oscillator, Self-Excited

(See Self-Excited Oscillator)

Oscillograph, Direct Writing

A recording instrument. The basic principle of most oscillographs is the D'Arsonval movement. This is essentially a suspended coil in a magnetic field. Current passing through the coil

imparts torque to the coil. A pen is attached to the coil to provide a record (direct writing). It has a long response time - about 0.01 sec being a maximum. Accuracies of about 10% may be expected in usual rocket applications.

Oscillograph Recorder

A device capable of charting high speed variations in measured quantities, such as vibration or pressure, as found in missile testing.

Oscilloscope

(See Cathode Ray Tube)

Outage

In a (usually ballistic) missile the propellant remaining in the tankage which cannot be used (e.g., converted into useful energy).

Outer Loop

A term describing the control loop including the missile and its guidance dynamics. This loop is outside the normal control system feedback loop which includes the aerodynamics of the missile. (See Fig. 10.25, p. 451)

Overcast

A term descriptive of the sky when it is more than 9/10 covered with clouds. Viewed from on top (aircraft view) it is said to be undercast.

Overpressure

The destructive pressure in the blast wave from an explosion, usually expressed in pounds per square inch above atmospheric pressure. During some period of the passage of the wave past a point, the over-pressure may be negative; that is, the absolute pressure at that point may be less than atmospheric pressure.

Overshoot

An occurrence in a control system when the control process exceeds the target value as operating conditions change.

Overshoot Factors

Aerodynamic factors which define the load applied to a surface or body as the result of maneuvers. The missile overshoots the desired angle of attack due to control system and aerodynamic damping characteristics.

Overtone

(1) A physical component of a complex sound having a frequency higher than that of the basic frequency.

(2) A component of a complex tone having a pitch higher than that of the fundamental pitch.

(3) The term overtone has frequently been used in place of harmonic, the nth harmonic being called the (n - 1) st overtone. There is, however, ambiguity sometimes in the numbering of components of a complex sound when the word overtone is employed. Moreover, the word tone has many different meanings so that it is preferable to employ terms which do not involve tone wherever possible.

(4) In a mechanical vibrating system with a set of normal modes of oscillation (e.g., a vibrating string) an overtone is a mode of frequency higher than the fundamental. The first overtone is the mode of frequency next higher than the fundamental, etc. (See Harmonic)

Oxidizer

That portion of the rocket propellant which provides the oxygen for combustion: e.g., liquid oxygen, nitric acid. (See Fig. 7.6.5, p. 301)

Ozone (O_3)

An allotropic form of oxygen. Used as an oxidizer in liquid propellant systems. (See Fig. 7.6.5, p. 301)

Ozonosphere

A region in the stratosphere having a relatively high concentration of ozone, occurring at a height of approximately between 15 and 22 miles, and important chiefly for its absorption of solar radiation. Sometimes termed the Ozone Layer or Ozone Stratum.

P

PDA

(See Pump Drive Assembly)

PDM

Pulse Duration Modulation. (See Telemetering, Pulse Duration Modulation)

p.e.

(See Probable Error)

PET
(See Production Environmental Testing)

P-I
(See Photogrametric Instrumentation)

PM
(See Modulation, Pulse)

PPI
(See Plan Position Indicator; Present Position Indicator)

PRF
(See Radar Pulse Repetition Frequencies)

PTM
(See Modulation, Pulse Time)

PWM
Pulse Width Modulation Telemetering (See Telemetering, Pulse Width Modulation; Telemetering, Pulse Duration Modulation)

P-Band
A radio frequency band of 225 to 390 megacycles with wave lengths of 133 to 77 centimeters, respectively. (Obsolescent) (See Fig. 6.5, p. 239)

Packaging
(1) Commercial: The art or operations required in the preparation of goods for shipment, storage, and delivery to the consumer. Involves protection against deterioration, mechanical damage, and pilferage; requires the use of container materials and facilities for the production and handling of packages and consideration of distribution and merchandising aspects.
(2) Military: Application or use of appropriate wrappings, cushionings, interior containers, and complete identification markings up to, but not including, the shipping container.
(3) Guided Missile Usage:
  (a) The assembly of parts, pieces and subassemblies into a package taking into consideration the environment, heat dissipation, maintenance, handling.
  (b) The orderly assembly of "boxes" or equipment into the missile.
  (c) The preparation for shipment.

Pad
(1) A nonadjustable attenuator. (See Attenuator)
(2) A resistance network used in coupling two impedances. Use of resistance rather than impedance results in a power loss, but gives coupling independent of frequency.
(3) A permanent or semipermanent base, usually concrete, constructed to support a missile-launching device.

Parallax Correction
A correction required because the location of a gun director or tracking radar is remote from the gun or missile launcher. Also required for missile guidance systems which determine position at the end of launch on the basis of ballistic information.

Parallel Cluster Missile
A descriptive term applied to missiles in which the sustainer and booster stages are side by side contrasted to a tandem arrangement.

Parameter
An arbitrary constant, as distinguished from a fixed or absolute constant; e.g., missile gross weight. Any desired numerical value may be given to a parameter.

Parametric Studies
Systematic approach to the evaluation of effects of variables or parameters on the design and performance of a missile.

Paraphase Amplifier
(See Amplifier, Paraphase)

Parasitic Oscillation
(See Oscillation, Parasitic)

Parhop
An instrumentation or measurement system utilizing the Doppler principle (without an airborne transponder) and depending on reflection of a continuous signal.

Parsec
A unit of distance with which astronomers compare stars on the basis of absolute magnitude, or the brightness of stars as if they were all at a distance of 10 parsecs (a parsec being nearly 3.26 light years) and photographic magnitude, or the brightness as it appears on a photographic plate.

Part

The smallest article; a piece of equipment which cannot be broken without losing its identify. e.g., tubes, resistors, capacitors, nuts, bolts, etc.

Pass Band (of a filter)

That band of frequencies which are passed with little or no attenuation.

Passive Electronic Countermeasures

(See Countermeasures, Passive Electronic)

Passive Jamming

(See Jamming, Passive)

Patching

The process of connecting one of the incoming electrical lines to one of the outgoing lines with a plugin cord or patchcord.

Patch Panel

A panel of electrical connectors some of which represent incoming lines - the remainder of which represent outgoing lines. A patch panel is used to permit flexible cross connections of systems, instrumentation, etc.

Pathfinder

A warhead delivered into a target area by superlative guidance which will then help guide less accurate missiles into the target area.

Payload

That portion of missile weight which is carried by the vehicle for the purpose of inflicting damage on the target. In the case of research and test vehicles, this includes instrumentation equipment for taking data and transmitting or recovering it.

Peak Overpressure

That maximum overpressure caused by a nuclear explosion at any given distance from Ground Zero.

Peak Pulse Power, Carrier-Frequency

The power averaged over that carrier-frequency cycle which occurs at the maximum of the pulse of power (usually one-half the maximum instantaneous power).

Peak Sound Pressure

(See Sound (Acoustomotive) Pressure)

Peclet's Number

The product δ R, where R = Reynold's number and δ = Prandtl number.

Pendulous Gyroscope Accelerometer

(See Accelerometer, Pendulous Gyroscope)

Pentode

A vacuum tube with five electrodes, usually: the cathode, control grid, screen grid, suppressor grid and anode.

Performance Index

(See Specific Fuel Consumption)

Performance Specification

A document which defines the performance of a guided missile system as contrasted with its design requirements.

Translation to Performance Specification. Once an operational requirement has been established for a guided missile it is then necessary to formulate a corresponding performance specification. This is a task for the materiel commands since such a specification will form the basis of a development contract. Actually, the prospective contractor often participates in this task, depending upon circumstances. Predicted performance is derived from an operational analysis of the proposed missile and is tempered by prior experience with similar missile developments. Sometimes it is determined that performance fully meeting the operational requirement cannot be attained under the current state of the art. In such cases lesser performance is generally accepted by the operational command as an interim goal.

Period

The time between each repetition of a complete vibratory phenomenon, i.e., between successive passages in the same direction across the position of rest. Mathematically, the period is the reciprocal of frequency.

Periodic Inspection

(See Inspection, Periodic)

Permanent Emplacement

In weapon system usage, a missile launching site with permanent features: e.g., antiaircraft sites to protect United States cities (Nike; ICBM sites in Zone of Interior (Z.I.); coast protection; etc.).

Permanent Set

A measure of the inability of a material to return to its original dimensions after removal of stress. Normally determined after sufficient stress is applied to produce a 0.2% strain.

Permanent Sites

Guided missile sites used for launching very large missiles, usually from the continental United States (Zone of Interior (Z.I.)).

Permeance

The susceptibility of a material to magnetic flow; the reciprocal of reluctance.

Perturbation

In space flight, the disturbance of an orbit by gravitational or other (e.g., drag) effects.

Perturbation Maneuver

(See Maneuver)

Perturbation Theory

The study of the effect of small disturbances on the behavior of a system.

Perturbative Force

In space flight, the resultant of all forces causing a disturbance of the orbit.

Petal Catchers

Devices used in shock tubes, pneumatic and hydraulic systems to capture burst diaphragm elements after rupture to avoid damage to the downstream system.

Phanastron

A circuit used for producing a rectangular pulse of known short duration.

Phantastron

(1) A monostable multivibrator used to generate very short pulses and linear sweeps.

(2) A certain type of one-tube relaxation oscillator employing Miller feedback to generate a linear timing waveform.

(3) This class of circuits has been termed Sanatron, Sanaphant.

Phantom Accelerations

The accelerations which a missile in flight experiences (1) because the earth is not a perfect sphere and (2) from the Coriolis effect.

Perveance

The saturation current which can flow in a vacuum tube. This current is proportional to the $\frac{3}{2}$ power of the applied potential.

Phase Margin

The phase magnitude at the frequency corresponding to unity gain is subtracted from 180° to obtain phase margin.

Phase Modulation

(See Modulation, Phase)

Phase Plane (Method)

A technique for analyzing servo performance. The response of a servo is plotted as a function of velocity vs. displacement (instead of displacement vs. time), for a variety of step amplitudes to provide a phase portrait in the phase plane. Note that phase does not relate to phase angle or phase shift associated with linear servo frequency.

Stability of the servo is determined from the phase portrait.

Phase Shift

A time difference between the input and output signal of a control unit or system.

Phase Splitting Circuit

A circuit that produces from the same input wave-form two output wave-forms that differ in phase from each other.

Phase, Terminal

(See Terminal Phase)

Phasing, System

(See System Phasing)

Phasitron

The name of a specialized electronic vacuum tube designed to provide phase modulation detection.

Photoelectron-Multiplier Tube

(See Electron-Multiplier Phototube)

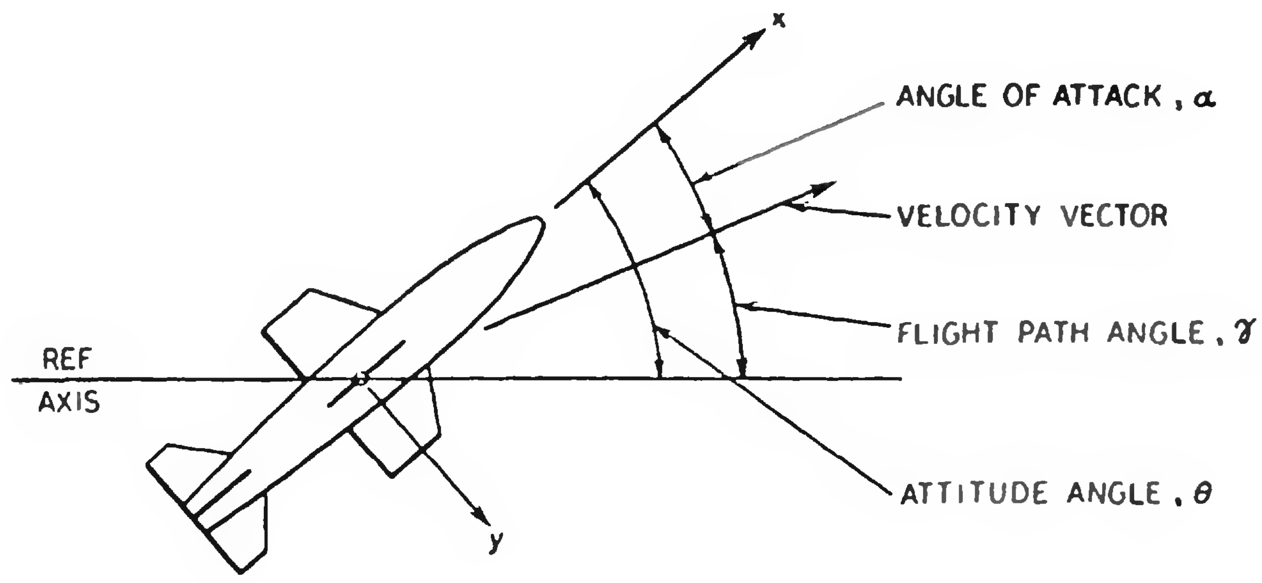
Photofission

(See Fission, Nuclear)

Photogrametric Instrumentation (P-I)

Any instrumentation that utilizes photographs for determining the position of an object, utilizing Ballistic camera, cinetheodolite, or Ribbon Frame cameras.

FIG. 10.45 PITCH ANGLE RELATIONSHIPS



Photon Rocket Engine
(See Rocket Engine)

Phototheodolite
Range instrumentation equipment used to track missiles optically. The missile image and angular coordinates are recorded against time (2 to 4 frames per second).

Phúgoid
(See Oscillation, Phugoid)

Physical Properties (Materials)
(See Mechanical Properties)

Pickoff
A device for converting mechanical motion into an electric signal proportional to the mechanical motion.

Pickup
A common expression for a transducer or end instrument.

Pigtail
A flexible metallic connection for electrical applications usually consisting of braided wire used between a stationary terminal and terminal having a limited range of motion.

Pilotless Aircraft
An aircraft which is equipped to function without a human pilot aboard. An obsolescent term for a guided mismile. Sometimes used to describe a drone.

Pinch Effect
When a large electrical current flows through ionized gas, the current filaments attract each other, which causes the gas column to constrict. The result is termed the pinch effect.

Pip
The figure presented on the oscilloscope of a radar caused by the echo from the target. Also termed blip.

Pitch
In aerodynamics, an angular displacement about an axis parallel to the lateral axis of an airframe. (See Fig. 10.45)

Plane of Polarization of a Radio Wave
A term which defines the orientation of energy in an electromagnetic wave; determined by convention to be the direction of the electric field with respect to the earth's surface.

Planetary Space
(See Space, Planetary)

Planetoid
One of the several hundred small planets revolving between the orbits of Mars and Jupiter; a body resembling a planet. (See Asteroid)

Plan Position Indicator (PPI)
A radar display in which targets are positioned in terms of azimuth and distance.

PI Mode
(See Mode, PI)

Plasma
A partially ionized jet, a mixture of gas and electrically charged particles (e.g., ions, electrons) at high temperatures.

Plastic Deformation
The permanent change in size or shape of a ductile material under stress. The deformation occurs along the slip planes of the crystals and anything that tends to interfere with this slippage or to resist the deformation will result in an increase in tensile strength.

Plasticizer

A material which is added to a rocket propellant to increase plasticity, workability, or to extend physical properties.

Plate

The common name for the principal anode of a vacuum tube.

Plate Circuit

A circuit including the plate voltage source and all other parts connected between the cathode and plate terminals of a radio tube.

Platform, Stabilized

(See Gyroscope, Stabilized Platform)

Playback

Playing back of a magnetic tape recording for the purpose of reconstructing the original signals as faithfully as possible.

Plotting Board

A device used to record the function of a variable usually in real time. (In missile applications, used to monitor range, target bearing, missile position, etc., by automatically plotting the variables.)

Plumbing

(1) In missile and radar usage, the designation for waveguides, coaxial lines and other equipment used for transmission of RF energy.
(2) The piping, lines and connections associated with the engine and its control.
(3) The piping lines and connections associated with the hydraulic system.

Plutonium Reactor

A nuclear reactor in which plutonium is the principal fissionable material.

Point Contact Transistor

(See Transistor, Point Contact)

Point, Image

(See Image Point)

Point, Impact

(See Impact Point)

Point-to-Point Wiring

A production technique for wiring electronic chassis in which the connections between components or parts are made without intermediate supports. (See Fig. 10.46)

Poisson's Probability Distribution

A mathematical expression of the distribution of random quantities often found in nature.

Polar Gnomomic Projection

In cartography, a method of portraying the earth's surface. If the pole is chosen as the point of tangency for a gnomomic projection, the meridians appear as radial lines and the parallels of latitude appear as concentric circles (Polar gnomomic chart).

Polarization, Vertical and Horizontal

In optics, to avoid ambiguity it is preferable to describe vertical and horizontal polarization as parallel and perpendicular, respectively, to the plane of incidence (the plane containing the incident and reflected rays).

Polyconic Projection

In cartography, a method of portraying the earth's surface. The projection is made on a series of cones tangent to the earth. Meridians, except the central one, are represented as curved lines. Parallels of latitude are nonconcentric circles, but having their centers along the central meridians, usually beyond the limit of the map.

There is no distortion along the central meridian and, unless the spread in longitude is great, maximum distortion is small. The polyconic projection is not suitable for navigational purposes because both direction and distance are difficult to measure accurately and both rhumb lines and great circles are curves.

Porous Reactor

(See Reactor, Porous)

Port Area

In rocketry, the cross-sectional area perpendicular to the longitudinal axis of rocket propellant grain available for free gas flow.

Position Data

Successive data defining the position of a target being tracked by radar or other means.

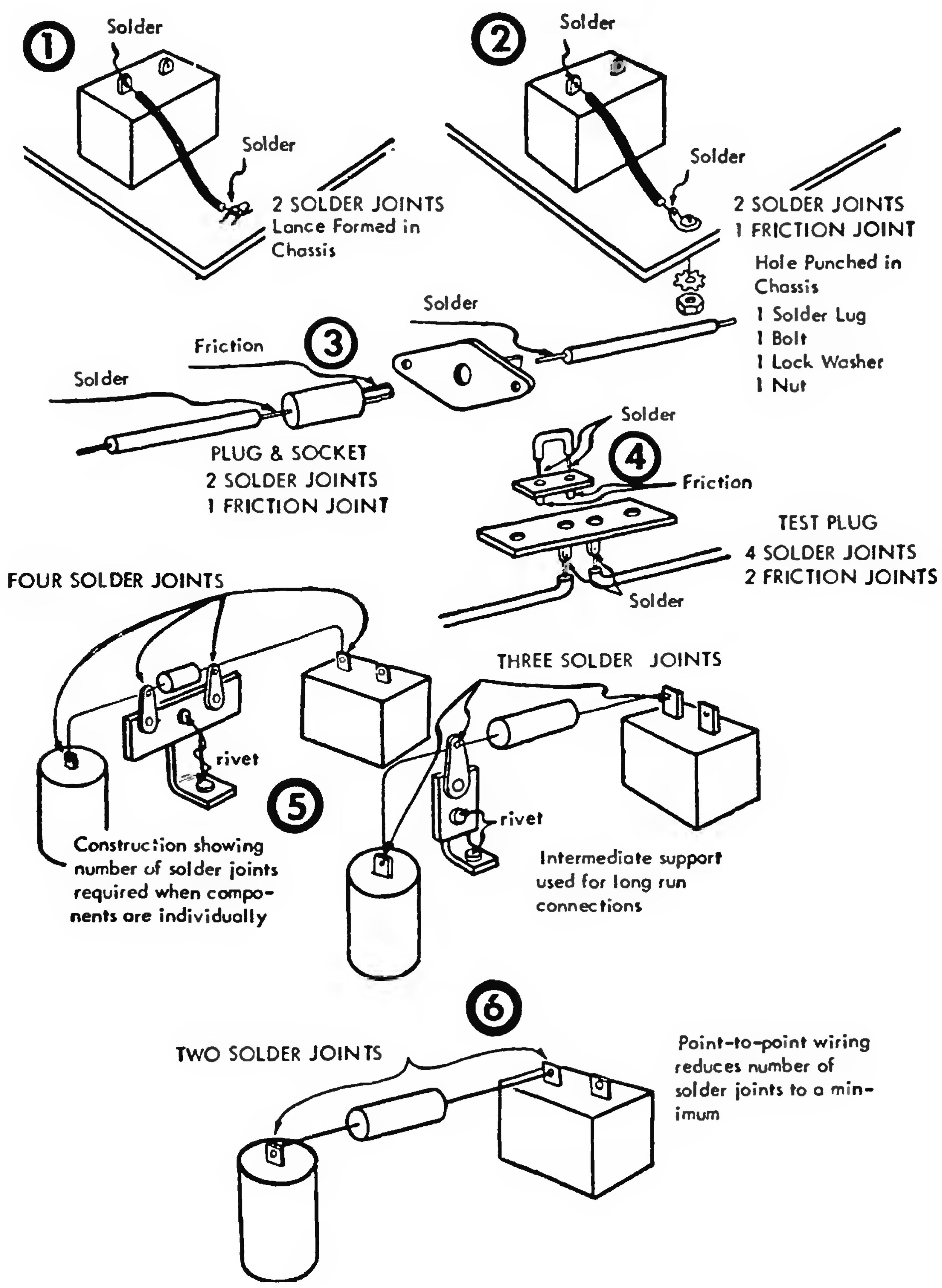
Position Feedback

(See Feedback, Position)

Positive Feedback

(See Feedback, Positive)

FIG. 10.46 COMPARISON OF POINT-TO-POINT WIRING WITH OTHER METHODS



Potentiometer

A device for translating a quantitative motion (angular or linear) into a proportional electrical resistance; it measures by comparing the difference between known and unknown electrical potentials.

Potting

The process of imbedding an electronic circuit component or assembly in a (usually) plastic material to reduce susceptability to deleterious environments, simplify maintenance, etc.

Power Spectral Density

Limiting mean square acceleration (velocity, displacement, stress or other random variable) per unit bandwidth, i.e., the limit of the mean square acceleration in a given rectangular bandwidth, divided by the bandwidth as the bandwidth approaches zero.

$$PSD = \lim_{\Delta f \to 0} \frac{a^2(\Delta f, f)}{\Delta f}$$

Power Standing Wave Ratio

(See Standing Wave Ratio)

Preamplifier

An extra stage of amplification at the front end of an amplifier or receiver used to increase signal strength.

Precession

A change in the orientation of the axis of a rotating body, such as a spinning projectile or gyroscope, the effect of which is to rotate this axis (axis of spin)

about a line (axis of precession) perpendicular to its original direction and to the axis (axis of torque) of the moment producing that change. (See Fig. 10.32, p. 455)

Precooling

(See Cooldown)

Predictor, Impact

(See Impact Predictor)

Pre-Launch Console

A pre-launch console is a display panel and control panel housed in the block-house that will automatically monitor or checkout the missile during a time interval prior to actual launch.

Preliminary Design

That design phase which has for its objective the establishment of the basic configuration and resultant performance of the missile and its auxiliary equipments.

Premature

A detonation of the warhead prior to the time that the S and A was to arm the system.

Preprototype

A device, article, assembly, or system which precedes the actual prototype. In terms of time, the preprototype usually follows the breadboard and is functionally correct in about the right package and proportion. Generally the device, et al, has not been designed for environment, maintenance and other features usually found in a prototype article.

Presented Target Area

The projection of the target upon the perpendicular plane used in defining the dispersion area; used to analyze the performance requirements of an armament system.

Present Position Indicator (PPI)

A device or system with computational features used to establish, for fire control or guidance systems, an indication of the present position of the missile target.

Pressure Feed System

In liquid rocket engines, the system used to cause the propellants to flow to the combustion chamber.

Pressure Front

(See Shock Front)

Pressure Limit

The upper and lower chamber pressure limit within which a solid propellant will operate satisfactorily.

Pressure, Sound (Acoustomotive)

(See Sound (Acoustomotive) Pressure)

Pressure Thrust

(See Thrust, Pressure)

Pressurize (Pressurization)

In pressure-fed propellant systems, that phase of operation in which the pressurizing gas is applied to the propellant to cause it to feed to the pumps or combustion chamber, or to prevent boiloff or vaporization.

Prestage

A phase in starting liquid rocket engines in which combustion is initiated and combustion chamber pressure is developed to a predetermined level at which time main stage is initiated.

Prevailing Westerlies

In meteorology, winds that blow toward the poles from the horse latitudes. They are not as steady as the trade winds in the Northern Hemisphere, but they are more constant in the Southern Hemisphere, where they are known as the Roaring Forties.

Primacord

An explosive charge, shaped like a rope. (Used in flight missiles to sever structure for flight termination purposes. Also used to sever control links, booster assemblies, etc.).

Primary Structure

The main framework, including fittings and attachments. Any structural member, the failure of which would seriously impair the safety of the missile, is a part of the primary structure.

Prime Contractor

A contractor having a contract directly with the Government or other funding agency. Contrast with a subcontractor who has a contract with a prime contractor.

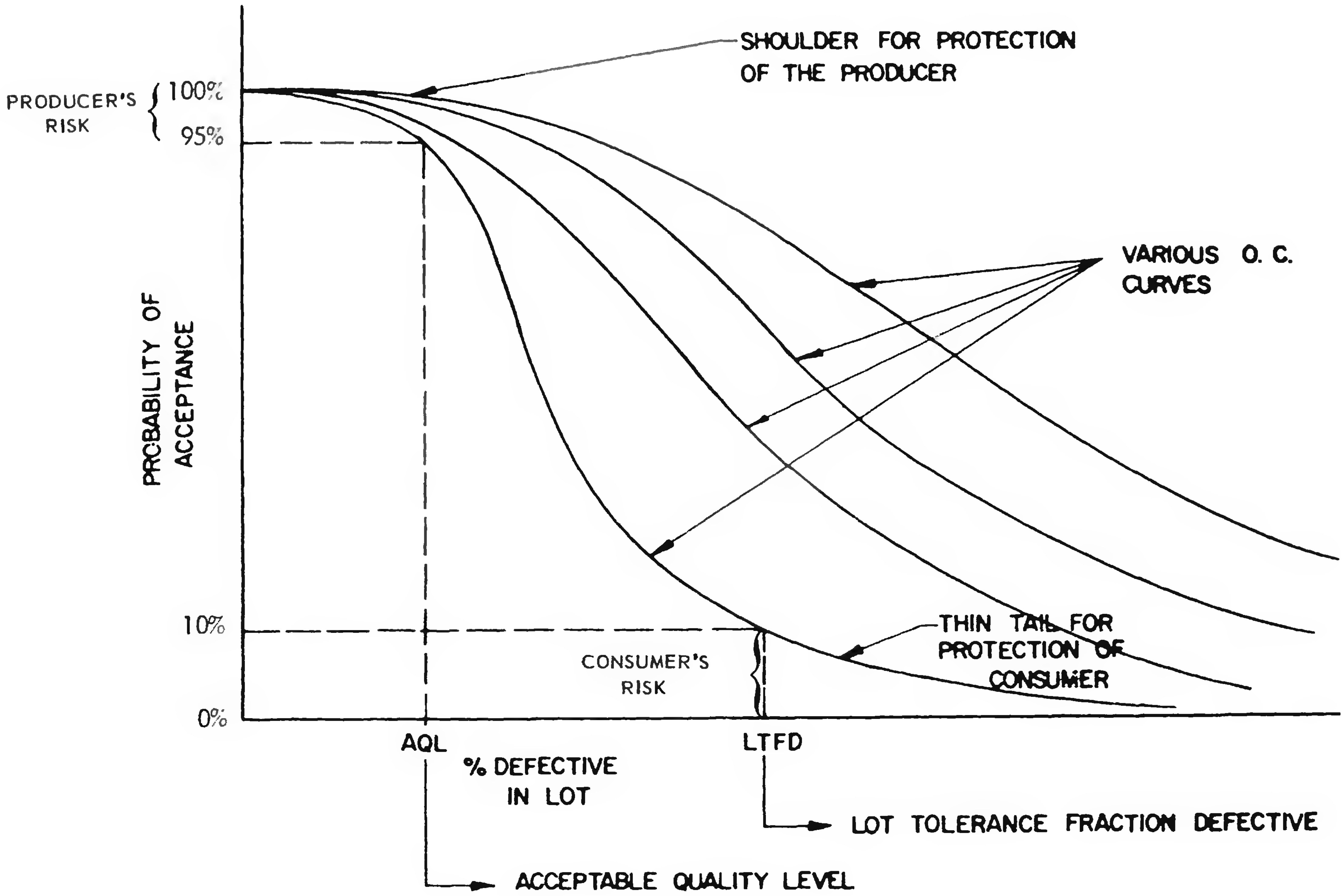
Primer

The first sensitive explosive element in an explosive chain which is initiated by low-level fuze output signals.

Principal Modes

(See Coupled Modes)

FIG. 10.50 TYPICAL OPERATING CHARACTERISTIC CURVES OF SAMPLING PLANS



Principal Planes

The three mutually perpendicular planes through a point in a stressed body on which the stresses are purely normal; i.e., tension or compression. Of these principal stresses, one is a maximum and one is a minimum. When one principal stress is zero, a state of plane stress exists; when two are zero, a state of uniaxial stress exists.

Printed Circuitry

A generic classification for fabricated wiring which may be obtained by:

- Metal to plastic laminate etching
- Silk Screening
- Photo-offset printing
- Plating
- Stamping
- Electro forming
- Embossing
- Spraying

Probability

The chance that a certain result will occur under a defined set of circumstances.

Probable Error (p.e.)

In a measurement system, the chance that fifty percent of the errors have absolute magnitude greater than the probable error.

Producer's Risk

The probability of risk of rejecting a lot, for a given lot quality or process quality, whichever is applicable. Usually applied only to quality values that are relatively good. (See Fig. 10.50)

Product Engineering

Translation of the development design into one suitable for efficient manufacture in the desired quantities and for the conditions of specified usage, handling, and life; the development and preparation of functional ordnance designs and/or specifications which are not only sufficiently clear and complete to represent the requirements and intent of research, but are also prepared in such manner as to facilitate efficient manufacture with the minimum of modification.

Product engineering includes such liaison with and direction over production engineering as to insure that the end product is suitable for service use, including all environmental considerations, and preparation of classification of defects.

Production

The manufacture of a finished device, built to definite specifications; the translation of the product engineering design into the desired quantity of the end product. Skilled engineering is frequently required during production to correct defects in design, to improve operating characteristics, or to increase rate of production. However, such engineering changes are based on the fundamental design created by development, which in turn was based on the facts discovered by research. The term production may be divided into the two following categories: (a) experimental production (including pilot line operation; (b) mass production (which includes the usual high production manufacturing operations).

Production Engineering

Consultation with product engineering on prototype or functional developments and designs and specifications and the making of recommendations that will promote maximum efficiency and economy in manufacture.

Participation in an advisory or consulting capacity in the preparation of detailed manufacturing drawings and specifications from which the missile can be most efficiently manufactured, having in mind not only the limited production required in time of peace but also the high rate of production with unskilled workers which is required in time of war.

The performance of the engineering function incident to efficient manufacture, such as tool and gage engineering, methods engineering, process engineering, production research, job standards.

Participation in the preparation of Classification of Defects for quality control purposes.

Production Environmental Testing (PET)

A test technique to check workmanship in which the article or system is subjected to a reduced intensity (compared to the design requirement) environmental test.

Production-to-Target Environment

(See Environment, Production-to-Target)

Production-to-Target Sequence

A chart or table showing all of the steps involved in manufacture, transport, storage, maintenance in storage, withdrawal from storage, assembly prior to launch, check-out prior to launch, launch, flight, and reentry.

Product Rule

The reliability of a system with n independent components can be calculated by multiplying the individual reliabilities together, i.e.,

$$R = R_1 \times R_2 \times \dots R_n$$

Program

(1) An entity; a definable portion of work; a scheduled development including study, design, fabrication and/or test phases.

(2) A pre-established and preset series of functions, maneuvers or operations: e.g., roll program, tilt over, gain change, etc.

Programmer

A device, either airborne or ground-based, used to control missile motion in accordance with a predetermined plan.

Progressive Burning

Burning of a solid propellant rocket grain characterized by an increasing pressure with time. (See Fig. 10.16, p. 423)

Proof Stress

The load per unit area which a material is capable of withstanding without experiencing a permanent deformation of more than a specified amount per unit of gage length after complete release of load; i.e., the stress that will produce a very small permanent deformation, generally specified as 0.01% of the original gage length. Because this is difficult to determine by the alternate loading and

releasing which is generally prescribed, the offset method is frequently employed.

Proof Test

An acceptance test for materials or parts in which a specified stress level must be sustained without deformation in excess of a specified amount.

Propagation

The manner in which an emission travels outward from its source.

Propagation Anomalies

Irregularities introduced into an electromagnetic or other sensing device by discontinuities in the medium of propagation.

Propagation, Velocity of Radio

The velocity of radio propagation. Within the accuracy demanded of radar equipment, usually taken as the velocity of light: 2.998×10^8 m/sec; 299.8 m/micro-sec; 186,296 miles/sec.

Propellant

The oxidant and fuel expended in a rocket to obtain propulsion. When the oxidant and fuel are combined in a single substance, this substance is termed a monopropellant.

Propellant, Auto-igniting

Any propellant that ignites at room temperature with adequately small time delay.

Propellant Composite

Propellants where oxidant and reductant occur as separate, distinct entities.

Propellant, Double-Base

A propellant consisting of nitrocellulose and nitroglycerin with the addition of certain stabilizers.

Propellant, Double-Base Powder

Solid rocket propellants consisting of gelatinized colloidal mixtures of nitroglycerin and nitrocellulose, to which certain stabilizers have been added. (See Fig. 7.5.1, p. 290)

Propellant, Heterogeneous

Propellants where oxidant and reductant occur as separate, distinct entities. (See Propellant, Composite)

Propellant, Homogeneous

A solid propellant rocket fuel in which the oxidant and reductant (or a mixture of monopropellant materials) occur as a single, or colloidal entity; often termed colloidal. An example of this type of propellant is ballistite or cordite where nitrocellulose is colloided with another mono-propellant such as nitroglycerin and other additives to provide the proper combustion characteristics and physical properties.

Propellant Loading Ratio (y_k)

(1) The ratio of propellant loaded on a missile to the gross weight of the missile.

(2) The ratio of the propellant loaded on a missile to the dry weight of the missile.

(Note that these commonly used definitions are quite different). (See Fig. 8.1, p. 312)

Propellant, Restricted

A propellant system where combustion takes place perpendicular to the longitudinal axis of the grain ("cigarette" fashion). Often termed end burner (or end burning grain). (See Fig. 10.16, p. 423)

Propellant, Rocket Engine

Material, consisting of fuel and oxidizer, either separate or together, liquid or solid, in a mixture or compound which, when suitably ignited, changes into a large volume of hot gases which, upon ejection through a nozzle, impart momentum to a rocket or missile.

Propellant, Single-Base

A nitrocellulose propellant.

Propellant, Trapped

(See Trapped Propellant)

Propellant, Unrestricted

A rocket propellant grain wherein combustion takes place on more than one planar surface. (See Fig. 10.16, p. 423)

Propellant Utilization System

A measuring system used in long-range rockets to insure that the fuel and oxidizer are consumed in the proper ratio so that a minimum residual propellant remains at the end of powered flight.

Proper

A fuze function which occurs within plus or minus three standard deviations of the normal distribution for fuze function.

Prop-Jet

(See Turboprop)

Proportional Navigation

(See Navigation, Proportional)

Propulsion, Jet

Any method for propelling a body which employs as its propulsive thrust the reaction force produced by the discharge of matter from the propelled body; the discharged matter being in the form of a jet of fluid.

Two general types of jet propulsion are utilized:

(a) The jet consisting of highly heated, compressed, atmospheric air, admixed with the products of the combustion produced by burning a fuel in the air; the thermal energy of the fuel being employed to raise the air temperature to the desired value. A jet of this type is termed a thermal jet. (See Thermal Jet Engine) (See Sec. 7, p. 273)

(b) The jet formed by generating large quantities of high-ressure, high-temperature gases by means of a chemical reaction which does not utilize atmospheric air. A gaseous jet produced in this manner is termed a rocket jet. (See Rocket Engine) (See Sec. 7, p. 273)

Propulsion, Rocket

(See Rocket Propulsion)

Propulsion System

The entire system required to propel a missile including the engine, accessories such as pumps and turbines, pressurization system, tankage and all related equipment.

Proton

An elementary particle having a positive charge equivalent to the negative charge of the electron but possessing a mass approximately 1845 times as great (1.00758 AMU). The proton is in effect the positive nucleus of the hydrogen atom and is a constituent of all nuclei.

Prototype

A model (of a guided missile or other equipment) that is suitable for complete evaluation of form, design, and performance. A prototype model utilizes approved parts and is representative of the final equipment. It follows an experimental model and precedes the production model.

Prototype Equipment

New equipment developed and produced to evaluate in service its suitability for establishing standards for production models.

Proximity Detector

(See Detector, Proximity)

Proximity Fuze

(See Fuze, Proximity)

Pseudoadiabat

The process in which saturated air is rising in the atmosphere and losing its water vapor by condensation and precipitation.

Pseudo-Integration

A means of determining the occurrence of a given minimum value of the time integral of acceleration.

p-Type Semiconductor

In solid state physics, an extrinsic semiconductor in which the hole density exceeds the conduction-electron density.

Pulse

The high power, short duration output of a pulse radar system: e.g., a sinusoidal voltage of VHF to EFH (100 to 30,000 mc, 3 m to 1 cm) is transmitted for a period of, typically, 1 microsecond.

Pulse Code

(1) The modulation imposed on a pulse train to convey information.

(2) Loosely, a code consisting of pulses, such as Morse code, Baudot code, Binary code.

Pulse Duration Modulation (PDM) Telemetering

(See Telemetering, Pulse Duration Modulation)

Pulsejet

A compressorless jet-propulsion device which produces thrust intermittently, with an operating frequency determined by the acoustic resonance of the engine. Consists of a pulsating

or intermittent inlet-valve system, a combustion chamber, and a discharge nozzle. Owing to the partial vacuum created for a short time in each cycle by the pulsating nature of the combustion and exhaust, this device can take in air and produce thrust even under static conditions.

Pulse Leading Edge

The major portion of the rise of a pulse of electrical energy.

Pulse Length

The time duration of the transmission of a pulse of energy, usually measured in microseconds or in the equivalent distance in yards, miles, etc., represented by the pulse signal on a radar-scope. (Short pulses of from 0.1 to 1 microsecond are usual for accurate radar work; longer pulses up to about 10 microseconds are used for less accurate work at greater ranges.)

Pulse Modulation

(See Modulation, Pulse)

Pulse Position Modulation

(See Modulation, Pulse Position)

Pulse, Radar

(See Radar Pulse)

Pulse, Radio-Frequency

A radio-frequency carrier, amplitude-modulated by a pulse. The amplitude of the modulated carrier is zero before and after the pulse. Coherence of the carrier (with itself) is not implied.

Pulse Repetition Frequency

The pulse repetition rate of a periodic pulse train.

Pulse Repetition Rate

The average number of pulses per unit of time.

Pulse Stretcher

A special video detector which converts a train of video pulses into a DC voltage upon which is superimposed an AC signal proportional to the modulation envelope of the pulse train. The AC component contains the angle information. The DC component is a function of average pulse amplitude and is used to control the receiver gain.

Pulse Time, Leading-Edge

The time at which the instantaneous amplitude first reaches a stated fraction of the peak pulse implitude.

Pulse Time Modulation

(See Modulation, Pulse Time)

Pulse Time, Trailing-Edge

The time at which the instantaneous amplitude of a pulse of electrical energy last reaches a stated fraction of the peak pulse amplitude.

Pulse Train

A series of pulses in digital representation of data.

Pulse Width

The time duration of any single electrical wave of an impulse type measured at a specific level. (In practice, the base pulse width is measured at ten percent of normal amplitude and the peak pulse width is measured at ninety percent of normal amplitude.

Pulse Width Modulation (PWM) Telemetering

(See Telemetering, Pulse Width Modulation)

Pump Drive Assembly (PDA)

An assembly used in liquid rocket propulsion systems consisting of the turbine, propellant pumps, gear boxes, power takeoffs and housing.

Pursuit Course

A homing guidance system in which the missile is directed along a flight path whose tangent coincides with the line-of-sight from missile seeker to target or deviates from it by a predetermined fixed angle. (See Fig. 10.47)

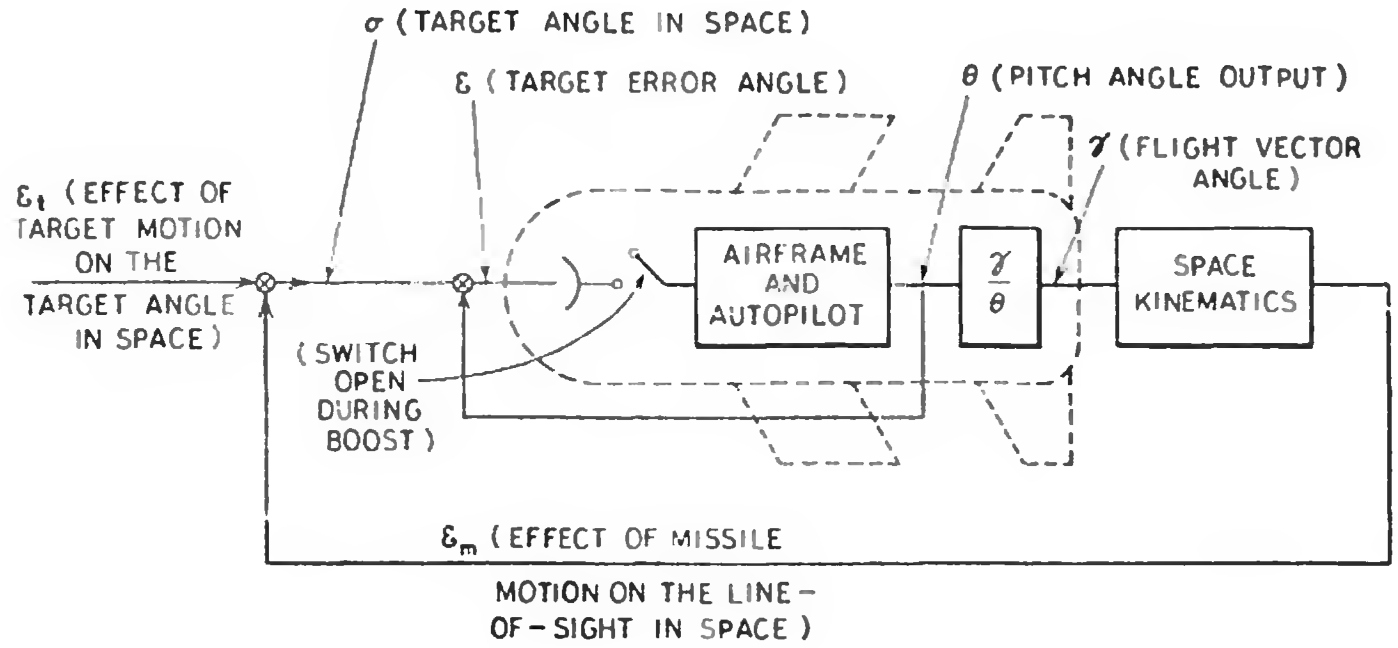
Pushover

(See Tilt Angle)

Push-pull Circuit

A two-tube amplifier circuit in which the grid and plate of one tube are operating 180° out of phase with the grid and plate of the other tube, as against parallel operation in which the grids are connected together and the plates are connected together. Push-pull operation generally results in higher output efficiency. Even order (2nd, 4th, etc.) harmonics are cancelled out. Hum in the plate supply circuit is balanced out. Push-pull

FIG. 10.47 FUNCTIONAL SCHEMATIC OF A PURSUIT NAVIGATION LOOP



circuits are used at both audio and radio frequencies.

Push-pull Oscillator

A vacuum-tube oscillator containing two tubes or a double-section tube connected in a phase relation similar to that of a push-pull amplifier.

Push-pull Parallel Circuit

A vacuum tube circuit consisting of four tubes (or two double section tubes) wherein the tubes are paired off in two's and connected grid and plates in parallel and then treated as two single tubes connected in push-pull. Mostly used in high-powered amplifiers.

Push-pull Transformer

An iron-core AF transformer designed for use in a push-pull amplifier circuit. If it is the input transformer, it will have a center-tapped secondary winding. If it is the output transformer, it will have a center-tapped primary winding.

Push-push Circuit

A two-tube amplifier circuit in which the grid of one tube operates 180° out of phase with the grid of the other tube, but the plates are connected together. Noted for fairly high efficiency when used for frequency doubling in radio frequency power amplifiers.

Pyrotechnic

A mixture of oxidant and reductant designed to produce light, heat, or perform some other non-propulsive function.

Q

Q

(1) A rating applied to coils, capacitors, and resonant electrical circuits, equal to reactance divided by resistance.
(2) The ratio of energy stored to energy dissipated per cycle in mechanical or electrical systems.
(3) In structural applications, the reciprocal of structural damping.
(4) A dimensionless parameter equal to the ratio, at the resonance frequency, of mass reactance ($2\pi fm$) to mechanical resistance (c) for a simple mechanical resonator or for a mass exhibiting some dissipation of energy under vibration; or the ratio of spring reactance ($k/2\pi f$) to mechanical resistance for a spring.

QOR

(See Qualitative Operational Requirement)

QPRI

(See Qualitative Personnel Requirements Information)

Quadrant Elevation

(See Elevation Quadrant)

Quadrature

Displaced 90° in phase angle. This is expressed by use of the letter j, which may be considered as an operator producing a rotation of 90° counterclockwise. Since j equals the square root of minus one, the square of j equals minus one. Thus two such operations would result in rotation of

180° or from plus to minus. An additional rotation of 90° (total 270°) results in minus j.

Qualified Component

A component (part, assembly) which has successfully passed a set of predetermined performance and environmental tests.

Qualitative Operational Requirement (QOR)

A formal statement of an essential operational need of an Air Force activity, including the broad characteristics of the item, system, technique needed to enable the Air Force to carry out its assigned mission more effectively.

Qualitative Personnel Requirements Information (QPRI)

Essential information about operational and position requirements from which qualitative personnel requirements (QPR) can be formulated. QPR consists of the specifications for human capabilities in a system and the characteristics whereby such capabilities can be obtained by means of position structure, selection, training, training devices, operating procedures, handbooks of instructions and other printed material.

Quality Control

That function which enforces compliance with engineering instructions, whether given by drawing, specification or other method. This includes responsibility for the proper execution of the following functions, with line authority varying according to company setup:

(a) Receiving inspection - technical or functional
(b) In-process inspection
(c) Process control - worker qualification
(d) Final inspection - Non-functional
(e) Functional inspection
(f) Material review: salvage or scrap

Quality Control is the agency to implement the requirements of the Engineering Department and Management on quality by establishing sample sizes, inspection intervals, detail acceptable limits, etc. from Engineering's more general specifications.

Quick Look Data

Those data provided at the end of a test on an expedited basis to permit rapid review of the test results. Such data in the form of approximately calibrated oscillograph or telemetering records, direct writing recorders and films are usually made available soon after the test.

R

RC Network

An electrical network of resistors and capacitors used in circuit design for capacitive-differential systems. Frequently the circuit time constant is such as to reduce the transient effect on the total response and the circuit response is essentially steady state.

RETMA

Radio, Electronics, and Television Manufacturers Association.

RF

(See Frequency, Radio)

RFA

Request for Alterations.

RGZ

(See Recommended Ground Zero)

RI

Radio Inertial (guidance system).

ROTI (Recording Optical Tracking Instrument)

Field instrumentation equipment for recording missile position by means of long focal length telescopes and camera.

RSO

Range Safety Officer.

R/V

Re-entry Vehicle.

Rack Panel

A standard metal or non-metal panel upon which is mounted electronic equipment. It fits into relay or rack cabinets. (Standard width is 19 in.; available in various heights which are always multiples of 1-3/4 in. Mounting notches are standard, to fit multiple-drilled racks and cabinets.)

Radar (Radio Detection and Ranging)

The principle of locating reflecting targets or objects by measurement of

reflections of radio-frequency energy from the targets. A term applied to devices which make use of the radar principle. (See Eq. 6.16, p. 242 and Fig. 6.9, p. 243)

Radar, Acquisition

A radar used for early warning of an impending attack. Acquires targets and in turn passes information to fire control radar(s) or to missile guidance radar(s).

Radar, Air Intercept (AI)

An interceptor-borne radar which normally permits search for, acquisition and tracking of a target and control of an air-to-air guided missile.

Radar, Beacon

(See Beacon, Radar)

Radar Beam

The space in front of a radar in which a target can effectively be detected and/or tracked. Its boundary is defined by custom as the loci of points, measured radially from the beam center, at which the power has decreased to one-half. (See Fig. 6.16, p. 249)

Radar, Clutter

(See Clutter, Radar)

Radar, Continuous Wave

A radar system in which a transmitter sends out a continuous flow of radio energy to the target which re-radiates (scatters) the energy intercepted and returns a small fraction to a receiving antenna. Since both the transmitter and receiver are operating simultaneously and continuously, it is sometimes impractical to employ a common antenna and usually two similar antennas are employed side-by-side and so oriented that only a small fraction of the transmitted power leaks directly into the receiver. The reflected wave is distinguished from the transmitted signal by the Doppler shift in radio frequency. The C-W method has two important properties:

(a) Its ability to distinguish moving targets against a stationary reflecting background.

(b) A narrow bandwidth as compared to pulse radar.

Radar, C-W

(See C-W Doppler Radar)

Radar, Dish

The reflector of the radar antenna; a shaped device usually placed behind the dipole for the purpose of shaping and directing the radar beam. (See Fig. 6.16, p. 249)

Radar, Doppler

(See Doppler Radar)

Radar Homing

A method of missile guidance wherein a missile-borne radar provides the required intelligence. (See Guidance, Homing; Guidance, Homing Active; Guidance, Homing Passive; Guidance, Semi-active)

Radar Horizon

The lowest elevation angle at which a radar can operate effectively owing to its line-of-sight propagation and the earth's curvature. (See Fig. 6.7, p. 241)

Radar Illumination (Semiactive Homing)

A method of missile guidance wherein a radar external to the missile but aimed at the target causes the target to emit echoes suitable for homing.

Radar, Lockon (Autotrack)

That condition of radar operation where it becomes possible to track a target by automatic rather than manual means.

Radar, Monopulse

A radar in which directivity is achieved by an antenna having several precisely spaced apertures - rather than by scanning. Phase comparison of the several signals yield direction.

Radar, Pulse

A radar which employs a transmitter that emits pulses of energy of vary short duration. By measuring the time interval between transmission of a pulse and the reception of an echo pulse, the range can be determined. Pulse radars can measure distances and survey several targets simultaneously. (See Eq. 6.16, p. 242)

Radar Pulse Repetition Frequencies (PRF)

The pulse repetition rates which occur in radars. They vary from approximately 200 to 2,000 per second. The ratio

pulse duration/total period from start of one pulse to the next

is called the duty cycle and in most installations lies between approximately 0.0005 and 0.002.

Radar, Reflection Interval

The length of time required for a radar pulse to travel from the source to the target and return to the source, taking the velocity of radio propagation to be equal to the velocity of light, 2.998×10^8 m/sec, or 299.8 m/microsec. Since the pulse must travel, in all, twice the distance to the target (out and back), the apparent velocities obtained are only one-half of the true velocity of the pulse. Likewise, the reflection intervals are just twice as great when target ranges are considered.

Radar Resolution

The ability of a radar to distinguish between a desired target and its surroundings.

Radar, Scan

A mode of radar operation wherein the beam direction is systematically changed in order to search for or track a target more effectively, e.g., circular, conical, spiral, helical, or rectangular.

A-scan - An indicator with a horizontal or vertical sweep, giving range only. Signals appear as deflections on the time scale.

B-scan - Type of presentation in which signal appears as a bright spot with azimuth angle as the horizontal coordinate and elevation angle as the vertical coordinate.

C-scan - Type of presentation in which signal appears as a bright spot with azimuth angle as the horizontal coordinate and elevation angle as the vertical coordinate.

D-scan - Presentation combining B and C types. The signal appears as a bright spot with azimuth angle as the horizontal coordinate and elevation angle as the vertical coordinate. Horizontal trace is expanded vertically by a compressed time sweep to facilitate separation of signal from noise and give a rough range indication.

E-scan - A modification of B-scan. Signal appears as a bright spot with range as horizontal and elevation as vertical coordinate.

F-scan - A single signal only, appearing as a bright spot. Azimuth error angle (relative bearing) appears as the horizontal coordinate, elevation angle as the vertical coordinate.

G-scan - A single signal only, appearing as a bright spot on which wings grow as the distance to the target is diminished. Azimuth angle appears as the horizontal and elevation angle as the vertical coordinate. This has been referred to as Mark VI indication.

H-scan - A modification of B-scan. Signal appears as a bright line the slope of which is proportional to the sine of the angle of elevation. Azimuth appears as the horizontal coordinate, and range as the vertical coordinate.

J-scan - A modification of type A in which the time sweep produces a circular range scale near the circumference of the CRT face. The signal appears as a radial deflection of the time trace. No bearing indication is given.

Radial Compressor

(See Centrifugal Compressor)

Radiation, Gamma (Ray)

In nucleonics, high-energy electromagnetic radiation with a wave length of about 10^{12} cm that has tremendous penetrating power and is dangerous to living tissues.

Radio Deception

(See Deception, Radio)

Radio Horizon

The distance to the radio horizon for a given antenna height. The effect of the earth's curvature can be taken into account, approximately, by assuming the radius of the earth to be 4/3 its actual value. For radio horizons over water the earth's radius should be doubled. (See Fig. 6.8, p. 242)

Radio-Inertial Guidance

(See Guidance, Radio-Inertial)

Radiometer

Any device for measuring the flux density of infrared radiation or total

radiant power falling on it. Radiometers usually comprise a sensitive detector, such as a thermocouple; an optical system, such as a paraboloidal mirror aluminized on its front surface, to form an image of an object or a selected area on the thermocouple; and some means of measuring the thermocouple voltage, such as a galvanometer or an ultra-sensitive voltmeter.

Radiosonde

An instrument which fulfills the same functions as the aerometeorograph but to much greater altitudes. A pilot balloon carries the instrument aloft; a parachute lowers it to earth again when the balloon bursts in the upper atmosphere. By means of a clockwork motor and very light weight radio-transmitting set, the indications of instruments sensitive to pressure, temperature and humidity are automatically transmitted at regular intervals during the flight. The signals from the radiosonde are received and recorded on a special receiver on the ground, and are then translated into readings of pressure, temperature and humidity at the various altitudes. Sometimes the instrument is tracked by radar to verify altitude.

Radio Wave - Plane of Polarization

In a propagated electromagnetic wave, the direction of the electric field with respect to the earth's surface.

Vertically polarized - electrical field is vertical

Horizontally polarized - electrical field is horizontal

Circularly polarized
Elliptically polarized } - electrical field is caused to rotate during propagation.

Radio Wave Scattering

Occurs when a radio wave strikes a surface too rough to support specular (or mirrorlike) reflection. Scattering may occur when a wave passes through a nonhomogeneous medium. Anomalies of the index of refraction of the earth's atmosphere produce some scattering. Scattering also occurs when a radio wave strikes raindrops, fog, hail or snow in the earth's atmosphere. Condensed water and other forms of precipitation are capable of both scattering the incident radiation and absorbing energy from the radio waves. The amount of energy which is lost by scattering is a function of the radio frequency and the size, shape, distribution, and index of refraction of the particles in the atmosphere.

Radius of Gyration

The square root of the ratio of the moment of inertia to the mass. If the mass of a body were concentrated at one point while preserving the same moment of inertia about an axis of rotation, the distance from this point to the axis of rotation would be the radius of gyration.

Radix

In communication theory, the total number of distinct marks or basic elements in a number system: e.g., binary system: 2; decimal system: 10.

Radome (RAdar DOME)

The housing for a radar antenna, essentially transparent to radio frequency.

Rail Type Launcher

(See Launcher, Rail Type)

Rain

Liquid water drops in the atmosphere ranging in diameter from 0.6 mm to approximately 5.0 mm, usually falling with velocities ranging from 3 m per sec. to 8 m per sec. Rain is the most common type of precipitation.

Ram Drag

In thermal jet engines, a quantity defining the drag induced by the air required for combustion. It is the product of the mass flow and flight velocity divided by the acceleration of gravity. (See Sec. 7.2, p. 280 and 7.3, p. 285)

Ramjet

A compressor-less jet-propulsion engine which depends for its operation on the air compression accomplished by the forward motion of the engine. Compared with current turbojet engines, the

ramjet engine offers (in its flight regime) certain advantages:
(a) The ramjet can produce a larger thrust per unit of maximum frontal area.
(B) Because of the absence of rotating machinery the ramjet engine can produce a larger thrust per unit of engine weight.
(c) The ramjet engine can be operated with a higher maximum temperature in its thermodynamic cycle. (See Fig. 10.48, p. 443 and Fig. 10.49, p. 512) (For a summary of ramjet design and performance equations see Sec. 7.2, p. 280)

Ram Pressure

The dynamic pressure or pressure at the inlet of an air-breathing engine resulting from its velocity through the air. It is the function of the air inlet and diffuser to decelerate the air entering the engine and transform a large portion of the kinetic energy of the air into a pressure rise.

Ram Rocket

(See Rocket, Ram)

Random Noise Testing

A test technique in which the forcing function applied (e.g., a driving signal to a shaker) is a complex wave of varying frequencies and amplitudes - usually, but not always, assumed to have a normal distribution in each octave. The signal may be obtained from an experimental source such as a missile telemetering record or may be made from a signal generator.

Range Instrumentation (and Range Safety Equipment)

Equipment used to obtain data from a test and/or to provide for flight termination. Such equipment normally is not part of an operational weapon system but may be included in modified or reduced capacity form.

Two categories are used:
(a) Active (airborne and ground equipment required)
(b) Passive (airborne and ground equipment required)

Range Safety

Those aspects of field testing relating to protection of life and property from guided missiles when fired at a test range.

Range Safety Equipment

(See Range Instrumentation)

Range Safety Systems

Systems which gather and present trajectory-position data of an airborne missile, and provide means of terminating missile flight in accordance with range safety regulations at missile test centers.

Range, Slant

(1) Line-of-sight distance from measuring point to target, especially an aerial target.
(2) The direct distance between an explosion and any given point.

Rate Action

In servomechanisms, a type of control action in which the rate of correction is made in proportion to how fast the condition has gone out of control. Also termed derivative action.

Ratio, Augmented Thrust

(See Augmented Thrust Ratio)

Ratrace

A particular type of radar waveguide configuration which serves the same purpose as the Magic Tee but allows the handling of greater power.

Raw Data

Data which are unprocessed. Data obtained directly from telemetering transmitters, range instrumentation, etc., which have not been calibrated, adjusted, compensated or otherwise reworked are termed raw data.

Rawinsonde

A balloon-borne transponder which is tracked as it rises for the purpose of determination of winds aloft.

Rayleigh Distribution

A mathematical statement of the distribution of random variables which occur often in nature.

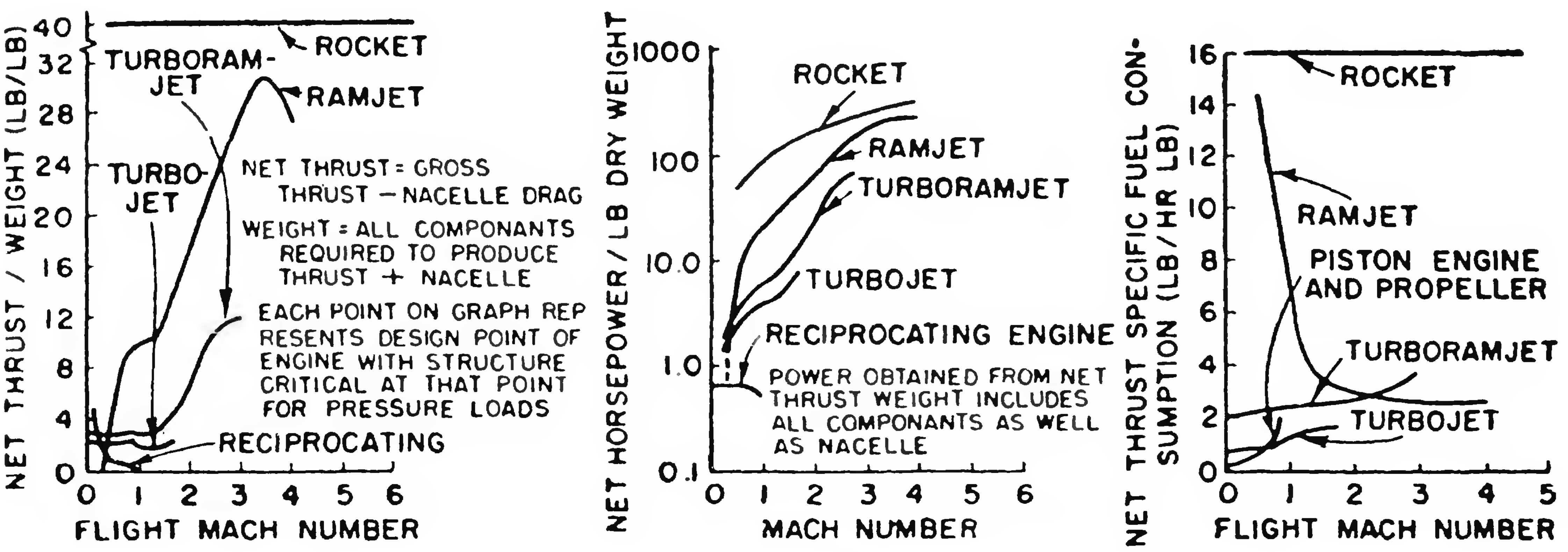
Rayleigh Pitot Equation

In aerodynamics, the ratio of stagnation to static pressure in air. (See Eq. 5.13, p. 217)

Rayleigh-Ritz Method

In mathematics, a variational principle for the solution of the eigenvalue equation $A\psi = \lambda B\psi$ (A, B, are

FIG. 10.49 COMPARISON OF DESIGN CHARACTERISTICS OF DIFFERENT PROPULSION ENGINES AS A FUNCTION OF THE FLIGHT MACH NUMBER



(a) COMPARISON OF RATIOS OF THRUST TO WEIGHT

(b) COMPARISON OF RATIOS OF POWER TO WEIGHT

(c) COMPARISON OF SPECIFIC FUEL CONSUMPTION

operators) based on taking as a trial function a linear combination of a complete set of functions, with coefficients which are to be varied to give the correct solution. (Used in aeroelasticity for computation of mode shapes and frequencies.)

Reactance

That component of the impedance of an electric circuit which is provided by the inductance (or capacitance); it varies directly as the frequency of the exciting current.

Reactance, Acoustical

The imaginary part of the acoustical impedance. The unit is the acoustical ohm.

Reactance, Electrical

In an electrical system the imaginary part of the electrical impedance. The unit is the abohm.

Reactance, Inductive

Reactance due to the inductance of a coil or other part in an alternating current circuit. Inductive reactance is measured in ohms, and is equal to the inductance in henrys multiplied by the frequency in cycles, times the number π. Inductive reactance therefore increases with frequency.

Reactance, Mechanical Rectilineal (Mechanical Reactance)

Mechanical rectilineal reactance is the imaginary part of the mechanical rectilineal impedance. The unit is the mechanical ohm.

Reactance, Mechanical Rotational (Rotational Reactance)

Mechanical rotation reactance is the imaginary part of the mechanical rotational impedance. The unit is the rotational ohm.

Reaction Turbine

A turbine which develops its power by the use of a high-pressure, low-velocity gas flow through the rotor blades. The pressure energy is converted to kinetic energy within the rotor blade passages.

Reactor, Atomic

A device designed to maintain a controlled nuclear chain reaction.

Reactor, Breeder

(See Breeding)

Reactor, Heterogeneous

A nuclear reactor in which the fissionable material and moderator are arranged as discrete bodies (usually according to a regular pattern) of such dimensions that a nonhomogeneous medium is presented to the neutrons: c.f., homogeneous reactor.

Reactor, Homogeneous

A nuclear reactor in which the fissionable material and moderator (if used) are combined in a mixture such that an effectively homogeneous medium is presented to the neutrons. Such a

mixture is represented either by a solution of fuel in the moderator or by discrete particles having dimensions small in comparison with the neutron mean free path, c.f.: heterogeneous reactor.

Reactor, High Flux

A nuclear reactor designed to operate with high neutron flux. Since a high flux results from a high rate of fission per unit volume, a high-flux reactor operates at high power density.

Reactor, Nuclear

An apparatus in which nuclear fission may be sustained in a self-supporting chain reaction. It includes fissionable material (fuel) such as uranium or plutonium, and moderating material (unless it is a fast reactor) and usually includes a reflector to conserve escaping neutrons, provision for heat removal and measuring and control elements. The terms pile and reactor have been used interchangeably, with reactor now becoming more common. They usually are applied only to systems in which the reaction proceeds at a controlled rate, but they also have been applied to bombs. Reactors sometimes are designated according to the fuel used (e.g., uranium reactor), or coolant (e.g., gas-cooled, liquid-metal cooled). The use of fusion in a reactor is speculative at this time.

Reactor, Porous

A nuclear reactor composed of a porous material or an aggregate of small particles with coolant or fluid fuel flowing through the pores.

Reactor, Thermal

A nuclear reactor in which fission is induced primarily by neutrons of such energy that they are in substantial thermal equilibrium with the material of the core. 0.025 electron volts (2200 meters per second) which corresponds to the mean energy of neutrons in a Maxwellian distribution at 293°K, often is taken as a representative energy for thermal neutrons, although most thermal reactors actually operate at a higher temperature. A moderator is an essential element of a thermal reactor.

Readied Missile

On which has been tested, fueled, warmed up, supplied with firing data and is prepared in all respects for activation of its firing sequence.

Readiness Time

The length or time required to obtain a stabilized system ready to perform its intended function. (Readiness time includes warm-up time.) The time is measured from the point when the system is unassembled or uninstalled to such time as it can be expected to perform as accurately as at any later time. Maintenance time is excluded from readiness time.

Read-Out

The means for extracting quantitative information from a device, e.g., elevation angle readout from a cinetheodolite is done by reading a photograph.

Ready Storage

Missile storage adjacent to the launcher or in such location that it is available to the handling equipment which will place it on the launcher. Tactical storage, testing, and ready storage conceivably may be in a single confined area and comprise one general operation if the circumstances so warrant.

Real Time

A term applied to the simulation of a guided missile operation on the same time scale as the actual operation.

Receiver Sensitivity

The lower limit of useful signal input to the receiver; set by the signal to noise (S/N) ratio at the output.

Reciprocity Theorem, Electric-Network

An equivalence theorem of value in electric network analysis. In an electric network composed of passive bilateral linear impedances, the ratio of an electromotive force introduced in any branch to the current measured in any other branch, called the transfer impedance, is equal in magnitude and phase to the ratio that would be observed if the positions of the electromotive force and the current were interchanged.

When altering the location of an electromotive force in a network, the branch into which the electromotive force is to be introduced must be opened, while the branch from which it has been removed must be closed.

Recommended Ground Zero (RGZ)

That point, with relation to the earth's surface, where it is recommended that a nuclear detonation take place in order to accomplish the desired effects.

Recovery

A generic term covering the means whereby a missile or a valuable part thereof can be recovered for analytical study and/or reuse. (The principal techniques are landing on wheels or a skid strip, lowering by parachute, recovery of a ruggedized data casette.)

Rectifier

An electrical device that conducts in one (the forward) direction and is an insulator in the opposite direction.

Rectifier, Full Wave

A radio tube, selenium rectifier, or other device which rectifies an alternating current in such a way that both halves of each input AC cycle appear in the pulsating rectified output. A full-wave rectifier tube contains two separate diode sections, one passing current during one alternation, and the other passing current during the opposite half cycle. Bridge rectifier circuits are often used for full-wave rectification.

Reduced Mass

In treating any two-body problem, the most absolute coordinate frame in which the laws of motion may be applied is an inertial system, i.e., a system which is not accelerated with respect to the fixed stars. The center of mass system of two bodies, having masses M and m and acted on only by mutual forces, is such an inertial system. When the equations of motion are transformed to center of mass coordinates, it is found that they are identical with equations in a system having its origin fixed at M if the mass m is replaced by the reduced mass, $\mu = Mm/(M+m)$. If $M \gg m$, the reduced mass is closely approximated by M.

Reduced Velocity

In flutter analysis, the ratio of airspeed to oscillation frequency of an aerodynamic surface.

Reduction of Area (%)

In a material subjected to stress, the difference between the original cross sectional area and that of the smallest area at the point of rupture. It is usually stated as a percentage of the original area; also termed contraction of area.

The reduction in area is a proper physical characteristic to describe ductility or degree of brittleness in a material.

Redundancy

The employment of multiple devices, structural elements, parts or mechanisms in combination (where each is capable of performing the same function) for the purpose of increasing the probability of occurrence and the reliability of the particular function or operation. It allows the adoption of more than one path in achieving a desired effect.

Reentry

That point in a body's trajectory where it first contacts the sensible atmosphere.

Reentry Body

That portion of a space traversing missile which usefully reenters the atmosphere. In a long-range ballistic missile, the separable reentry body contains the heat shield, warhead, attitude stabilizing and fuzing equipments needed to: reenter the earth's atmosphere without self-destruction from a very high velocity and altitude; reduce the dispersion and explode the warhead.

Reflective Code

(See Gray Code)

Reflector, Confusion

A reflector of electromagnetic radiation used to create echoes for confusion purposes against radars, guided missiles, and proximity fuzes. (See Chaff; Meaconing; Rope; Window)

Reflex Circuit

A circuit in which the signal is amplified, both before and after detection, in the same amplifier tube or tubes.

Reflex Klystron

A klystron in which the two resonant circuits of a conventional klystron are confined into a single resonant cavity, which now acts also as anode. As an oscillator, the reflex klystron possesses the advantage of having only one tuned circuit to be adjusted. Also it is possible to make small adjustments to the frequency by altering the voltage on the repellent. (The tuning range obtainable in this way is small, of the order of about one per cent.)

Regeneration

A method of securing increased output from an RF amplifier by feeding part of the output back to the amplifier input in such a way that reinforcement of the input signal is obtained. With this arrangement, a signal may pass through the same amplifier over and over again, with a resultant increase in amplitude. Causes oscillation when carried to extremes.

Regressive Burning

Burning of a solid propellant rocket grain characterized by a decreasing pressure versus time characteristic. (See Fig. 10.16, p. 423)

Relative Humidity

(See Humidity)

Relaxation Oscillator

(1) Generally, an oscillator having a decidedly non-sinusoidal output, resulting from abrupt transitions from one unstable state to another.
(2) An oscillator in which the frequency is controlled by the charge or discharge of an inductor or capacitor through a resistor.
(3) A multi-vibrator oscillator circuit employing two tubes (or a double section tube) with resistance-capacitance coupling between the tubes to feed the output back and forth between them. Used in television circuits to generate sweep voltages for cathode-ray tubes.

Relaxation Time

The time period for equilibrium of molecular action in a flow field; about 0.0001 sec for oxygen and 0.00002 sec for nitrogen.

Relay

An electromagnetic switch employing an armature to open or close contactors. A small current through the coil actuating the armature thus can control a heavy duty circuit at the contactors.

Reliability

The probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered. If the product rule is used the over-all reliability is based on the product of the individual reliabilities of each element: e.g., 100 components (if independent) with a 99% reliability each will have an over-all reliability of 36.5%.

Overall Reliability = $q_1 \cdot q_2 \cdot q_3 \cdot q_4 \ldots q_N$

Where $q_1 = (1-p_1)$, etc.

p_1 = probability of component failure at some random time

q_1 = probability that component will not fail at this random time

n = number of such components in series

N = number of different classes of independent components in series.

(SeeFunctional Reliability) (See Fig. 3.15, p. 94)

Reliability, Cumulative

The concept of establishing reliability by weighting or use of the learning curve; the heaviest emphasis is on the last missile or system tested (i.e., the one with the most advanced state of development, the most learning, etc.)

In one approach the weights assigned the reliability of successive articles are as follows:

$$R = \frac{\sqrt{1}\, R_1 + \sqrt{2}\, R_2 + \sqrt{3}\, R_3 + \text{---} \sqrt{n}\, R_n}{\sqrt{1} + \sqrt{2} + \sqrt{3} + \text{---} \sqrt{n}}$$

where R_c = cumulative reliability

$R_1 \ldots R_n$ = reliability of each missile

Reliability, Functional

The probability that all components, units, or major units in a system will function within their specified operating tolerances for a specified length of time and under specified environments.

Relief Valve

(See Valve, Relief)

Reluctance

The resistance of a material to magnetic flow; the reciprocal of permeance.

Repeater Jammer

(See Jammer, Repeater)

Reproducibility

(1) In instrument work, the exactness with which a measurement of a given value can be duplicated.

(2) In manufacturing, the degree to which parts, assemblies, etc. can be duplicated.

Requirements, Force

The manpower and personnel required by an armed service using a weapon system for a defined mission.

Requirements, Operational

The need of an armed service for a specified weapon system.

Research

A continued process of scientific investigation prior to and during development. It has for its aim the discovery of new scientific facts, techniques, and natural laws.

Research, Applied

Research aimed at specific application of scientific laws, principles, and phenomena. In contrast to basic research, the prospect of practical application of the results is a primary motive for applied research. Frequently even the methods to be used are clear before work is begun.

Research, Basic

The theoretical or experimental study directed toward the increase of knowledge. It may result in the discovery of new scientific phenomena, principles, techniques, or significant data which add to the store of scientific knowledge. Immediate practical application is not necessarily a direct objective.

Research, Nonmateriel

Research directed toward development or improvement of techniques, rather than toward the development of materiel. It includes such subjects as the application of psychology or of analytical and statistical methods to the study of military problems.

Research, Operations

The scientific, qualitative, quantitative study of warfare by military agencies with the objective of improving the weapons, tactics, and strategy of future operations through analysis and evaluation of past operations and maneuvers and operations trials. Also known as Operational Research, Operations Analysis, and Operations Evaluation.

Residual Contamination

Nuclear radiation remaining after an atomic warhead detonation. Usually refers to radiation from the cloud or from fission products deposited on the ground.

Resilience, Modulus of

The energy stored in a cubic inch of an elastic material at the bottoming point of that material when under stress.

Resistance, Mechanical Rectilineal (Mechanical Resistance)

Mechanical rectilineal resistance is the real part of the mechanical rectilineal impedance. This is the part responsible for the dissipation of energy. The unit is the mechanical ohm.

Resistance, Mechanical Rotational (Rotational Resistance)

Mechanical rotational resistance is the real part of the mechanical rotational impedance. This is the part responsible for the dissipation of energy. The unit is the rotational ohm.

Resistor

An electrical part which offers resistance to the flow of electric current. Its electrical size is specified in ohms or megohms (one megohm equals 1,000,000 ohms). A resistor also has a power-handling rating in watts, indicating the amount of power which can safely be dissipated as heat by the resistor.

Resnatron

A high-power, high-efficiency, cavity-resonator tetrode designed to operate in the VHF region. Principle of operation is similar to that of a class C oscillator, with careful attention to beam focusing playing a large part in the high efficiencies achieved.

Resojet
(See Pulsejet)

Resonance (or Resonant Frequency)
That frequency at which the magnification factor is at a maximum. Normally occurs when the natural frequency of the item and the forcing frequency are the same.

Resonant Burning
In solid rocket design, the phenomenon of unstable combustion vibration resulting in acoustical resonance. (More commonly termed chugging or screaming.)

Responder
(See Beacon)

Restricted Area
A security or classified area to which access is controlled.

Restricted Burning Grain
A solid propellant rocket grain in which the burning surface is restricted or inhibited to provide particular pressure-time characteristics. (See Fig. 10.16, p. 423)

Restricted Data
A security classification for all data concerning the manufacture or utilization of atomic weapons, the production of fissionable material, or the use of fissionable material in the production of power, but not including any data which the Atomic Energy Commission from time to time determines may be published without adversely affecting the common defense and security.

Restricted Propellant
(See Propellant, Restricted)

Retractable Launcher
(See Launcher, Retractable)

Retrofit (Backfit)
A modification of a missile or other equipment to incorporate changes made in later production of a similar piece of equipment. Retrofitting may be done in the factory or field.

Retro Launching
Launching a missile backward relative to its parent airplane.

Retro Rockets
Rocket units, usually solid propellant type, used to retard one body relative to another: e.g., fired opposite to main power units to separate burned out stages.

Rhumbatron
A resonant cavity (used instead of circuits) consisting of lumped inductance and capacitance, to act as an oscillator capable of giving several kilowatts output at frequencies of several thousands of megacycles.

Rhumb Line
In cartography, the line making the same angle with all meridians.

Rhumb Line Distance
Distance measured along a rhumb line, i.e., a line on the surface of the earth making the same angle with all meridians.

Rime (ice)
In meteorology, a rough or feathery coating of ice deposited by fog on terrestrial objects.

Ring Modulator
A rectifier modulator (demodulator) employing four diode elements connected in series to form a ring. The diodes are connected with a polarity which will readily permit current flow around the ring in one direction. Appropriate input and output connections are made to the four nodal points of the ring. The ring modulator is also termed the double-balanced modulator. It can serve as a balanced modulator as well as a phase-sensitive detector or demodulator.

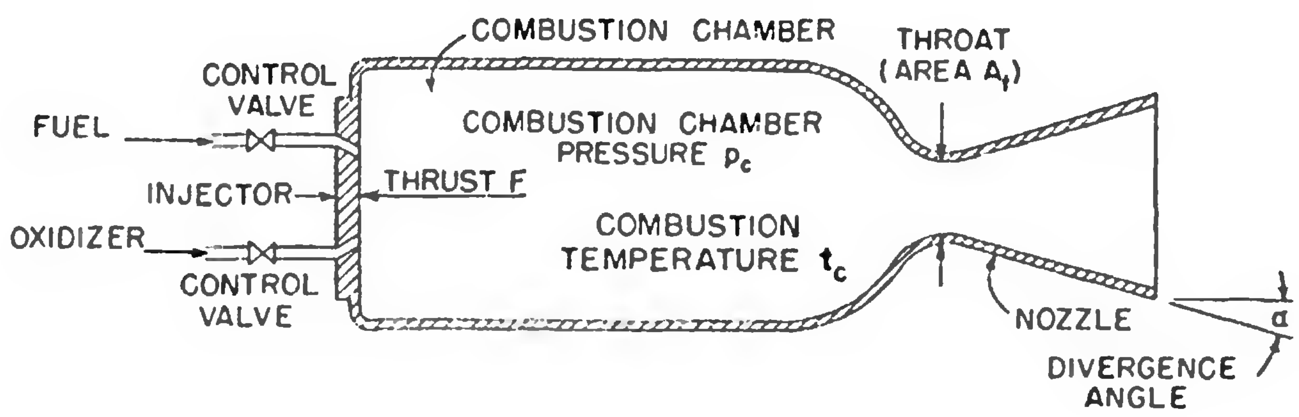
Ripple
The alternating-current component present in the output of a direct-current generator, rectifier system or power supply.

Ripple Fire
The launching of guided missiles in short succession.

Risk
The probability of making an incorrect decision.

Risk (Producers and Consumers)
A concept used in reliability and test activities to avoid having either the consumer or the producer accept most of the risk for the acceptability of the product. The concept is based on the probability that the consumer will accept a defective product so many times and

FIG. 10.51 PRINCIPAL ELEMENTS OF A ROCKET MOTOR



that he will reject a good product so many times; also that the producer will deliver with a certain probability a defective product or that he will reject a good product. (See Fig. 10.50, p. 501)

Robot Pilot

(See Automatic Pilot)

Rocket

A thrust-producing system which derives its thrust from ejection of hot gases generated from material carried in the system, not requiring intake of any outside oxidizing agent. (See Rocket Engine, Rocket Propulsion) (See Fig. 10.51)

Rocket, Booster

(See Boster Rocket)

Rocket, Ducted Solid Propellant

A type of missile propulsion system which uses a solid reductant (fuel) contained in a duct with air serving as the oxidant. This type of rocket is known as a solid propellant ramjet and is not a pure rocket system; i.e., it is an air-breathing engine.

Rocket Engine

(1) A type of propulsive device which develops thrust independently of the medium in which it operates. The classes are:

(a) Liquid propellant rocket engine (all of the propellants being in the liquid state prior to their injection into the rocket motor).

(b) Solid propellant rocket engine (the chemicals being in the solid state before chemical reaction is initiated).

(c) Nuclear rocket engine (a nuclear reactor being used to accelerate a self-contained fluid).

(d) Photon rocket engine (a source of light photons being used to develop thrust).

(See Fig. 10.11, p. 408 and 10.52, p. 479)

(2) A propulsive component of a guided missile. In rocket usage that part of the propulsive system which actually produces the thrust. Includes auxiliary pumps and drives and is a self-contained unit but does not include the tankage, pressurization or control systems.

(See Fig. 10.53, p. 448)

Rocket Engine, Liquid Propellant

A rocket engine in which all of the propellants are in a liquid state prior to their injection into the combustion chamber.

Rocket Engine (or Propulsion System)

A complete power plant consisting of one or more thrust chambers and related pumping, pressurization and control equipment.

Rocket Engine, Solid Propellant

(See Solid Propellant Rocket Engine)

Rocket, Hybrid

A solid propellant rocket employing either an auxiliary liquid propellant or some other working fluid, e.g., air.

Rocket Motor

(See Motor, Rocket)

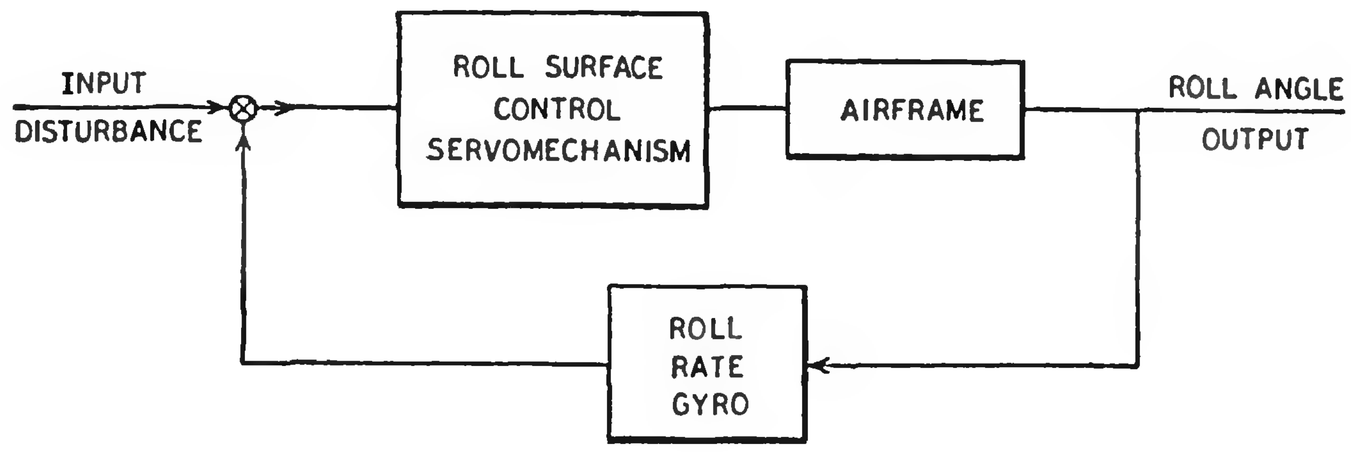
Rocket, Multistage

A rocket or rocket missile having two or more thrust-producing units each used for different states of the rocket's flight. (Normally, each unit of a multistage rocket is jettisoned when fuel is consumed.)

Rocket Propulsion

The means whereby thrust is developed by a rocket engine; i.e., the fundamental principle upon which all propulsion prime movers operate is based on Newton's third law; for every action there is an equal and opposite reaction.

FIG. 10.54 ROLL CONTROL BLOCK DIAGRAM



Upon combustion of the propellants in the burning chamber, the gases expand through the nozzle at a high velocity, the internal pressure at the nozzle end is relieved, causing an unbalanced pressure at the other end which tends to move the chamber and vehicle to which it is mounted in the direction opposite to the issuing jet. Propulsion is dependent upon internal conditions alone and not the effect of the jet "pushing" against the surrounding air.

Rocket, Ram

An integral Jato-ramjet combination in which the rocket is utilized for obtaining operating speed for the ramjet.

Rocket Sled

A sled propelled along a fixed track by rockets to permit acceleration and/ or high speed tests (e.g. SMART, SNORT).

Rocket, Sounding

A meteorological rocket used to gather atmospheric data at various altitudes.

Rockoon

A balloon-supported and launched rocket used for high altitude research. Deacon rockets are lifted by a Skyhook balloon to high altitudes where the instrumented rocket is then fired to still higher altitudes.

Roentgen

The absolute unit of X- or gamma-ray dosage used for measuring radiation exposure. That quantity of X-ray of gamma radiation which produces 109 ion pairs/cc of air or, in the body, the production of 10^{12} ion pairs/gm of tissue.

Roll Control

Missiles are stabilized in appropriate axes to permit resolution of guidance signals. Intelligence is obtained from a reference system such as gyros (free; rate or in combination with networks) and control is obtained from aerodynamic surfaces (separate rollerons, differential motion of wing or tail superimposed on pitch and yaw motions); or from gimballed rocket engines operating differ entially. (See Fig. 10.54)

ROMOTAR

Similar to DORAN, a measuring system using fewer modulating frequencies than DORAN. It obtains direct slant range by employing a ground station receiver located at the same point as the transmitter.

Ronchi (Technique)

A method of evaluating Schlieren photographs utilizing a grating with opaque lines.

Rope

Reflectors of electromagnetic radiation consisting of long strips of metal foil. A small parachute or other device may be attached to each strip to reduce the rate of fall. (See Reflector, Confusion)

Roti (Recording Optical Tracking Instrument) (Mk I and Mk II)

Field instrumentation equipment for recording missile position in space by means of two long focal length, large aperture, telescopes. Cameras record the missile image and azimuth and elevation dials versus time.

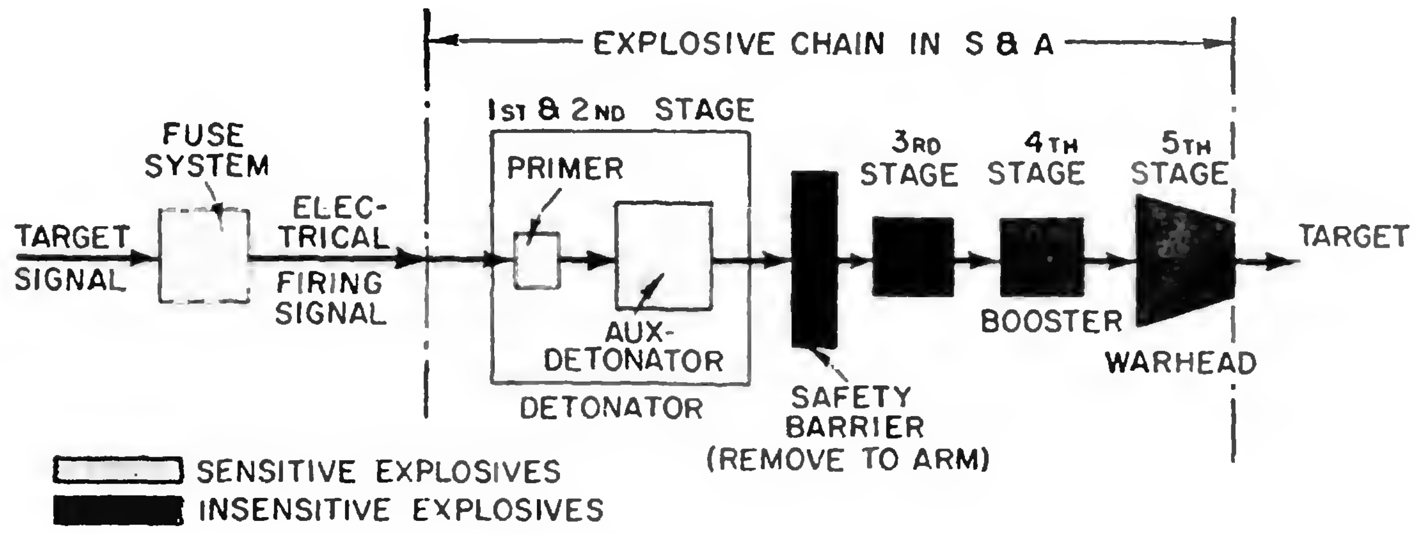
Round

Artillery terminology for a single projectile or missile.

Ruggedization

A technique used to improve the ability of a device or equipment to withstand a severe environment.

FIG. 10.55 EXPLOSIVE AMPLIFIER CHAIN PROVIDED BY S & A



S

SAGE
(See SemiAutomatic Ground Environment)

SAM (Surface-to-Air Missile)
(See Missile, Ground-to-Air; Missile, Guided; Model Designation)

S and A
(See Safety and Arming Mechanism)

S-Band
A radio-frequency band of 1,550 to 5,200 megacycles with wave lengths of 19.35 to 5.77 centimeters respectively. (See Fig. 6.5, p. 239)

SI
Shipping Instructions (Sometimes ASI-Amended Shipping Instructions.)

SLOE
(See Special List of Equipment)

SM
(See Missile, Strategic)

S-N Curves
In materials testing, the curves obtained by plotting the number of cycles (N) as abscissa against the load per square inch (S) applied to the test specimen as ordinate. They graphically illustrate the effect of rapid reversals of stress of definite value on the life of the specimen.

S/N Ratio
(See Signal to Noise Ratio)

SOP
Standing Operating Procedure.

SSIP
Sub-System Integration Plan.

SSM (Surface-to-Surface Missile)
(See Missile, Ground-to-Ground; Missile, Guided; Model Designation)

SUM (Surface-to-Underwater Missile)
(See Missile, Ground-to-Ground; Model Designation)

SWEL
Special Weapons Equipment List.

SWR
(See Standing Wave Ratio)

Sabin
In acoustics, a unit of equivalent absorption equal in its absorbing effect to 1 sq ft of a completely absorbing surface; i.e., one that does not reflect sound waves.

Sabot
A thrust transmitting attachment which serves as a gas seal for the propellant gas and positions and drives a projectile in the bore of a gun or tube.

Safe-Time
The time during which the S and A is in the unarmed condition, i.e., prevents warhead detonation by fuze action. The period during which warhead detonation cannot occur by fuze action.

Safety and Arming Mechanism (S and A)
A device to interrupt the functional path between fuze and warhead until after proper launching has taken place and until the missile has passed beyond nearby friendly forces; arming consists of completing the functional path at the proper time. (See Fig. 10.55)

Safety Factor
(1) In structural design, the ratio of ultimate load to limit load.
(2) The extent of a unit's capacity to withstand loads or other inputs in excess of those normally expected to be applied.

Safety Fuse
(See Bickford Fuse)

Salvo Fire
The launching of guided missiles simultaneously in groups.

Sanaphant
(See Phantastron)

Sanatron
(See Phantastron)

Satellite
A smaller body revolving around another, generally a planet.

Satellite Orbit
(See Orbit, Satellite)

Satellite Vehicle
A vehicle made to revolve about the earth in order to gather scientific data.

Satelloid
A satellite vehicle usually intended to be kept in its orbit by low thrust motors.

Saturable Reactor
In electrical devices, an inductive passive element whose value of impedance may be controlled by regulating the degree of saturation of a ferromagnetic core.

Saturate
(1) The overwhelming of defensive firepower by sheer numbers of weapons.
(2) The overwhelming of any automatic device by excessive inputs.

Saw-tooth Generator
A neon or thyratron relaxation oscillator or a vacuum tube oscillator providing an alternating voltage characterized by a saw-tooth waveform.

Scale Effect
An effect in fluid flow, that results from changing the scale, but not the shape, of a body around which the flow passes. Correction of this effect is by application of the Reynolds number.

Scale Factor
(1) In analog computing, a proportionality factor which relates the magnitude of a variable to its representation within a computer.
(2) In digital computing, the arbitrary factor which may be associated with numbers in a computer to adjust the position of the radix so that the significant digits occupy specified columns.
(3) A measure of the sensitivity or merit of an instrument; e.g., a galvanometer or similar device where it is the rate of the current through, or the voltage across, the terminals to the deflection.

Scaling Law
A formula which permits the calculation of some property for a given article based on data obtained from a similar, but different size, article; e.g., crater size, nuclear radiation, etc., for a nuclear warhead of any yield from the known values for another yield.

Scanning Antenna Mount
A mechanical support for an antenna which provides mechanical means for scanning or tracking with the antenna, and means to readout information for indication and control.

Scanning, Circular
Scanning in which the direction of maximum radiation (beam axis) generates a plane or a right circular cone whose vertex angle may approach 180°.

Scanning, Conical
Scanning in which the direction of maximum radiation (beam axis) generates a cone whose vertex angle is of the order of the beam width. Such scanning may be either rotating or nutating, depending upon whether the direction of polarization rotates or remains unchanged.

Scan, Radar
(See Radar, Scan)

Schematic Diagram
A presentation of the element-by-element relationship of all parts of a system.

Schematic Drawing
A line drawing showing the interconnection of the various circuits within a component using conventional sumbols to represent the detail parts.

Schlieren
A photographic technique used to record high-speed gas density discontinuities, gradients or variations in gas density, or striae (from the German word). Schlieren are made visible by an optical system which either cuts off or passes a large change in light intensity owing to the slight refraction of the light passing through the gas. This system is often used in wind tunnels making visible turbulence and weak shock waves by showing the first derivatives of gas density directly.

Schmoo Plotting
Plots which show the operating margins when the component under test is varied between its upper and lower "end of life" limits while all other components are at the worst end of the initial acceptance tolerances.

Schottky Effect
Lowering of the surface barrier by an electric field. The lowering of the work function due to an applied accelerating field. It is responsible for a noticeable increase in emission current as the applied voltage is increased.

Schuler Pendulum
(See Earth Pendulum)

Scintillation Counter
A device consisting of several transparent phosphors together with a photo multiplier tube, which detects ionizing particles or radiation by means of the light flash emitted when the radiation is absorbed in the phosphors.

Scopodromic
On the target course; homing, or heading in the sighted direction.

Scorsby Table
A two degree of freedom random motion table used for testing gyroscope drift.

Screaming Combustion
A combustion instability in jet engines producing relatively high-frequency pressure oscillations and auditory effects.

Scrub
In missile parlance, a cancelled flight test.

Secor
A range instrumentation system designed to provide distance and position information. A missile borne transponder is interrogated by a ground station and the answer received by several stations to provide distance data. Angle measurement is provided by phase comparison techniques. The system was developed by the Cubic Corporation.

Security
Methods and means for preserving secrecy, including access to classified information.

Seeker, Target
(See Guidance, Homing)

Self-Destruction
Actuation of destructive agents to destroy the missile in the event of a target miss or other abortion of the particular mission.

Self-Destruction Equipment
Some type of explosive, in a circuit such that it may be exploded by (a) a time-delay mechanism, (b) a radio-command link, (c) an automatic trip mechanism actuated by engine cutoff, loss of a signal, etc.

Self-Destruct Signal
(See Command-Destruct Signal)

Self-excited Oscillator
A vacuum-tube oscillator that operates without external excitation and solely by the direct voltages applied to the electrodes.

SELSYN (SELf SYNchronous)
A General Electric Company trade name for a synchro. (See Synchro)

SemiAutomatic Ground Environment (SAGE)
A defense system providing instantaneous information needed for control of missiles and aircraft used to wage air battles. A Massachusetts Institute of Technology Lincoln Laboratory development.

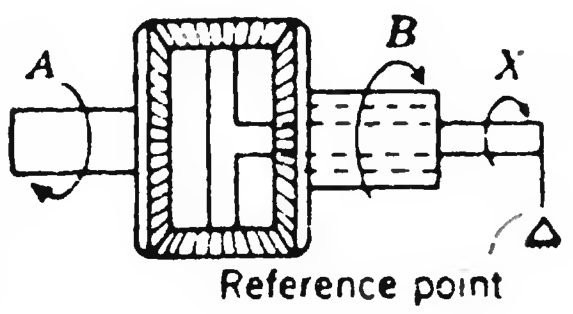
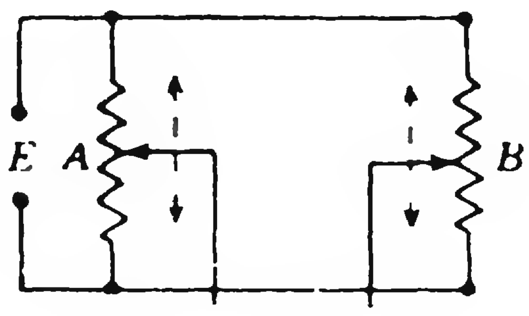
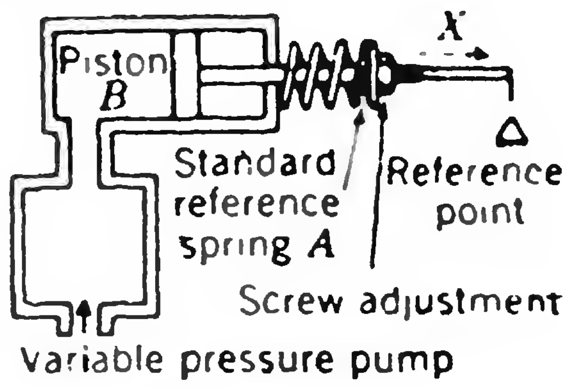
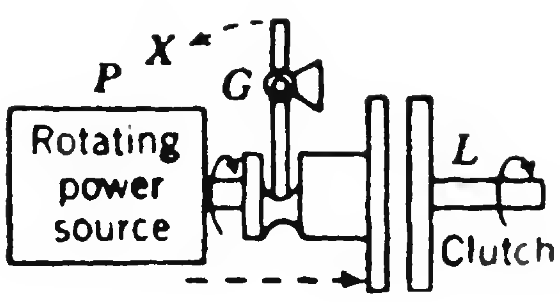
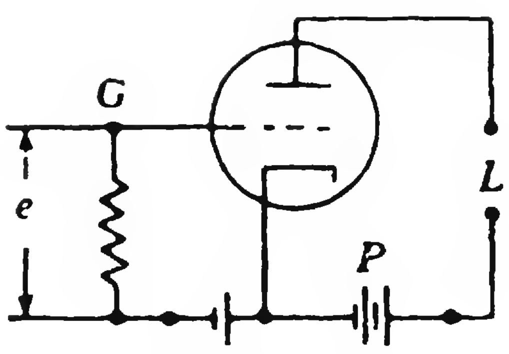
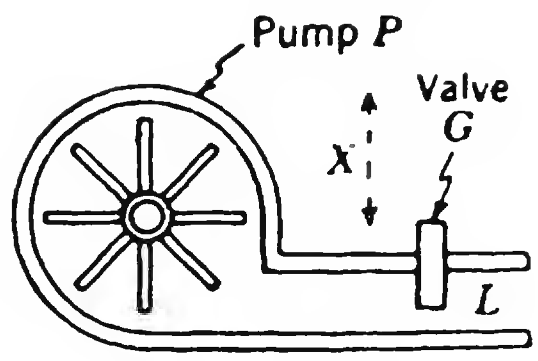
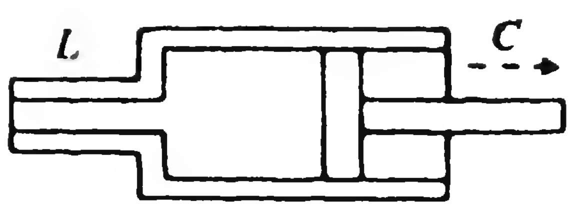
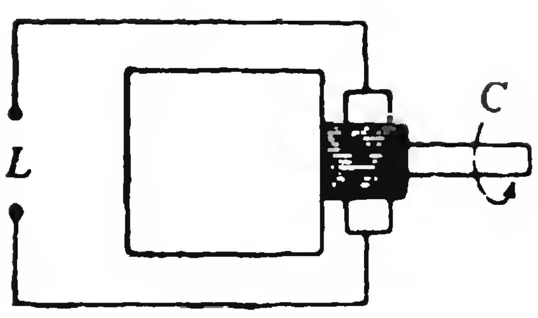
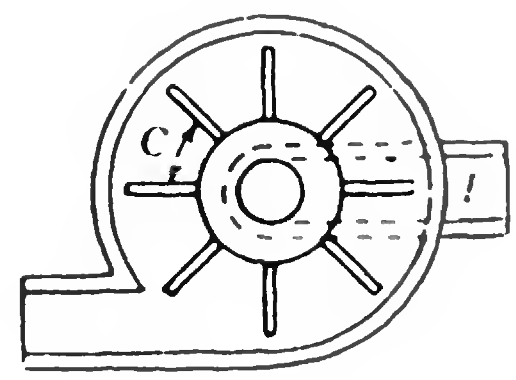
Semiconductor
An electrical conductor with resistivity in the range between metals and insulators, in which the electrical charge carrier concentration increases with increasing temperature over some temperature range. (See j-Type Semiconductor; n-Type Semiconductor; p-Type Semiconductor)

Semi-monococque
A structure in which sheet and stringers are used in conjunction to provide a stiff load carrying cell. The longerons divide the sheet into small panels with correspondingly improved buckling resistance.

Sensitivity
The degree of response of an instrument or control unit to a change in the incoming signal.

Separation
(1) The phenomenon in which the boundary layer of the flow over a body placed

FIG. 10.56 TYPICAL SERVO COMPONENTS

Component class	System: Mechanical	System: Electrical	System: Hydraulic
(a) Error-measuring device	 Differential: Error displacement X appears when regulated output position B changes relative to input position A	 Resistance bridge: Error voltage E appears when regulated position of contact B changes relative to input position of contact A	 Piston: Error displacement X appears when regulated output pressure at B differs from input pressure of spring A
(b) Amplifier	 Clutch: Small force at X controls large energy output from power source P to local L	 Electronic tube: Small error voltage controls large energy output from power source P to load L	 Valve: small force displacing valve G through X controls large energy output from pump P to load L
(c) Error-correcting device	 Piston: Converts amplified output L into correcting force C	 Electric motor converts amplified voltage output L into correcting torque C	 Hydraulic motor: Converts amplified pressure L into shaft torque C

Abstracted from S. W. Herwald, Forms and Principles of Servomechanisms, Westinghouse Engr., September, 1946.

in a moving stream of fluid separates from the surface of the body allowing a condition of low energy turbulent air to exist in the region between the body and the smooth flow.

(2) Regarding multistage missiles, the action time or place at which a burned-out stage is discarded and the remaining missile continues on its way.

Serviceability

The degree to which a missile or equipment is susceptible to use by armed forces personnel. It involves simplicity of design and consequent absence of superfluous members or components, specification of adequate and reliable elements for trouble-free service life, accessibility of critical components, and use of standard parts where possible. Ease of maintenance, readiness with which adjustments can be made, ease of accurate alignment of parts, ease of handling and loading, and man similar criteria are also included.

Service Test

(1) A test, under simulated or actual conditions, to determine the characteristics, capabilities, and limitations of a given piece of equipment or materiel.

(2) A similar test made of a plan, method of doing something, or organization.

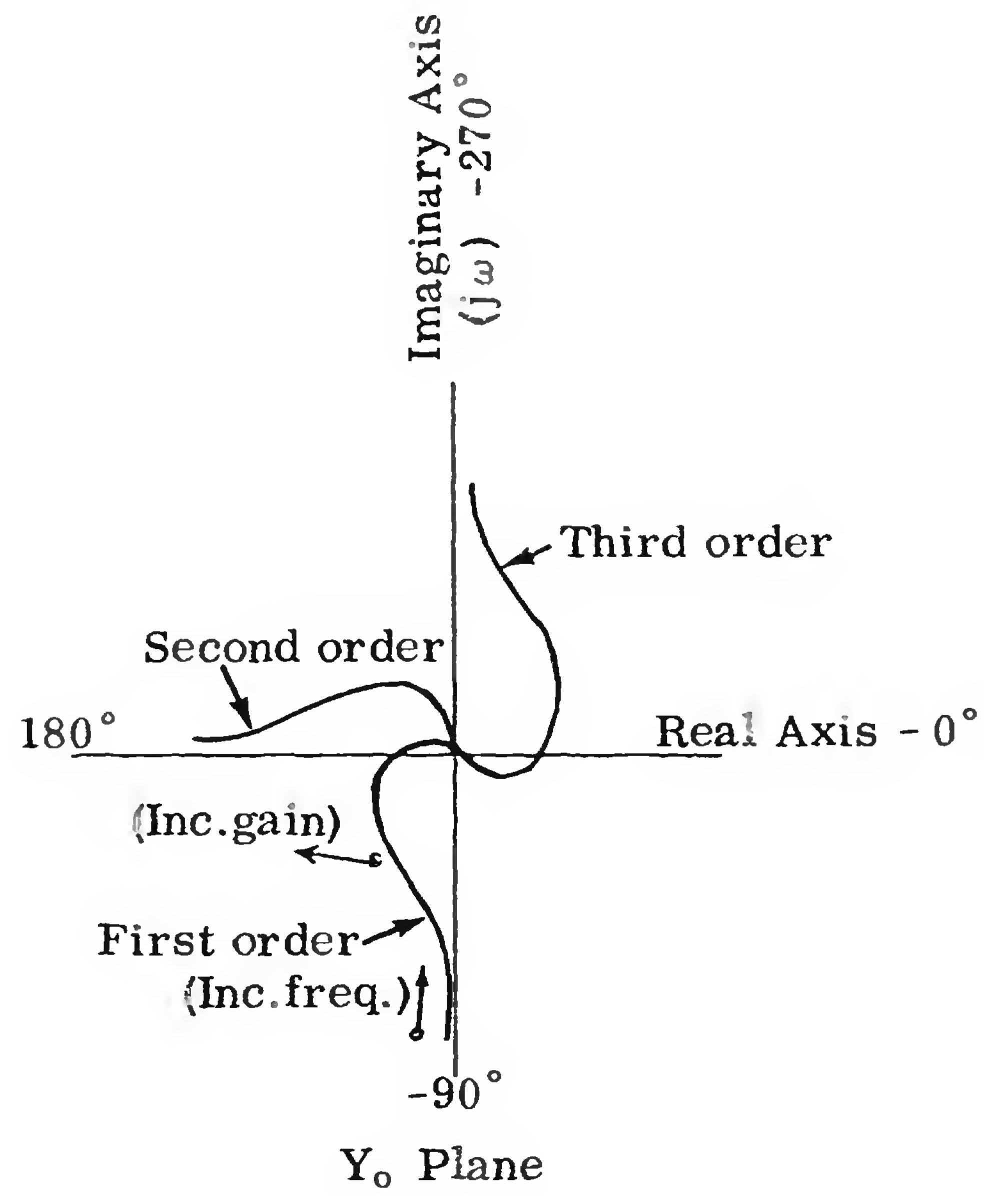
(3) An operational suitability test, especially when used as an attribute, e.g., service-test guided missile.

(4) A test made at any point in the development of a piece of equipment or materiel, with the object of predetermining, if possible, ultimate capability and serviceability; i.e., any test made during the research and development stage, or a test to see if a contractor has complied with specifications, or a test on refined or modified material.

Servo

A combination of devices for controlling a source of power in which the output (or some function thereof) is fed back and compared to some reference at the input, the difference of this comparison being an error signal used to effect the desired control. (See Fig. 10.56, p. 523)

FIG. 10.57 GENERALIZED NYQUIST PLOTS FOR FIRST, SECOND & THIRD ORDER SERVOS



Servo Corner Frequency

The frequency at which the break in the slope of an open loop characteristic curve occurs.

Servomechanism

A servo used to control a mechanical function.

Servo Order

Classes of servos:

First - A servo with a zero static error, but a finite steady following error to a velocity input.

Second - A servo with a zero steady following error for a step velocity input. It has one time lag in the loop. (Termed zero velocity error servo.)

Third - Similar to a second order servo with two time lags in the loop.

(See Fig. 10.57)

Servo, Stable

A servo system in which the output is always finite, or limited, for any finite input. Most servos are stable only if the open loop transfer function gain is less than unity at any frequency at which the

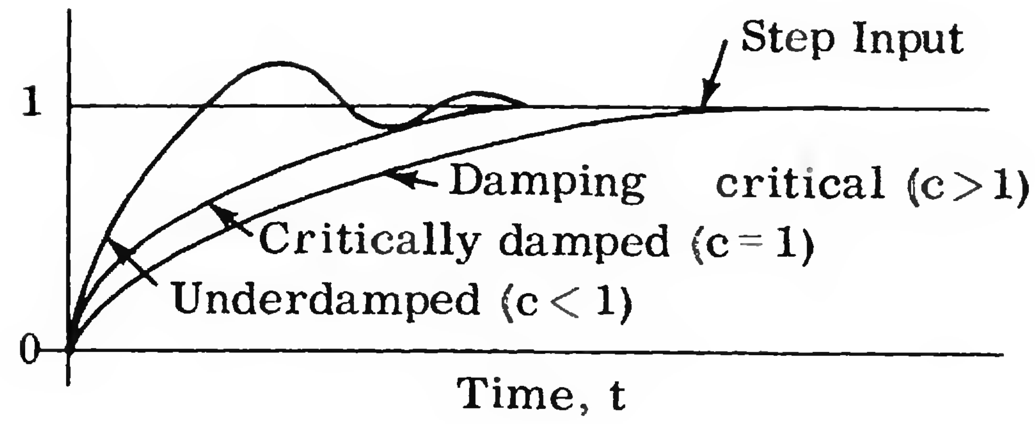
FIG. 10.58 GENERALIZED RESPONSE TO A STEP INPUT

$c = \frac{F}{2\sqrt{KJ}}$ Roots

$s^2 + 2c\omega_o s + \omega_o{}^2 = 0$

$c > 1$	$r_1 = -\omega_o c + \omega_o \sqrt{c^2 - 1}$
	$r_2 = -\omega_o c - \omega_o \sqrt{c^2 - 1}$
$c < 1$	$r_1 = -\omega_o c + j\omega_o \sqrt{1 - c^2}$
	$r_2 = -\omega_o c - j\omega_o \sqrt{1 - c^2}$
$c = 1$	$r_1 = -\omega_o c$
	$r_2 = -\omega_o c$

where c = relative damping factor
F = viscous friction coefficient
K = gain
J = load inertia



open loop transfer function phase angle is 180 degrees. (See Fig. 10.61)

Servo System

An error reducing closed-cycle automatic-control system so designed that the output element or output quantity follows as closely as desired the input to the system. The output is caused to follow the input by the action of the servo-controller upon the output element in such a way as to cause the instantaneous error, or difference between output and input to approach zero. All servo-systems are dynamic systems containing at least one feed-back loop which provides an input signal proportional to the deviation of the actual output from the desired output; this property distinguishes servo-systems from ordinary automatic-control systems.

In general, servo-mechanisms exhibit the following properties:

(a) Include power amplification.
(b) Are "error sensitive" operation.
(c) Are capable of following rapid variations of input.

(See Fig. 10.58)

Servo Table

A precision test table, servo-driven at a rate to eliminate the effect of the earth's rotation when properly aligned, and used to evaluate drift rates of gyroscopes.

Servo, Unstable

A servo in which the output drifts away from the input without limit.

Servo, Velocity Limiting

A servomechanism in which the performance is limited by the velocity (or rate) attainable by the servo.

Shaped-Charge

A type of warhead based on the Munroe effect, which focuses explosive forces into very sharp beams of high gain.

Shear Lag

In box and wide flange beams, the difference in shear from that predicted by elementary theory. Flange bending stresses on a wide flange beam may not be constant along a line parallel to the neutral axis. The shear stresses, which are related to the bending stresses will not correspond to those predicted by elementary theory — this is the shear lag.

Sheet Stiffener

In airframe construction, the combination of thin cover or surface plates or skin reinforced by longitudinal stiffeners.

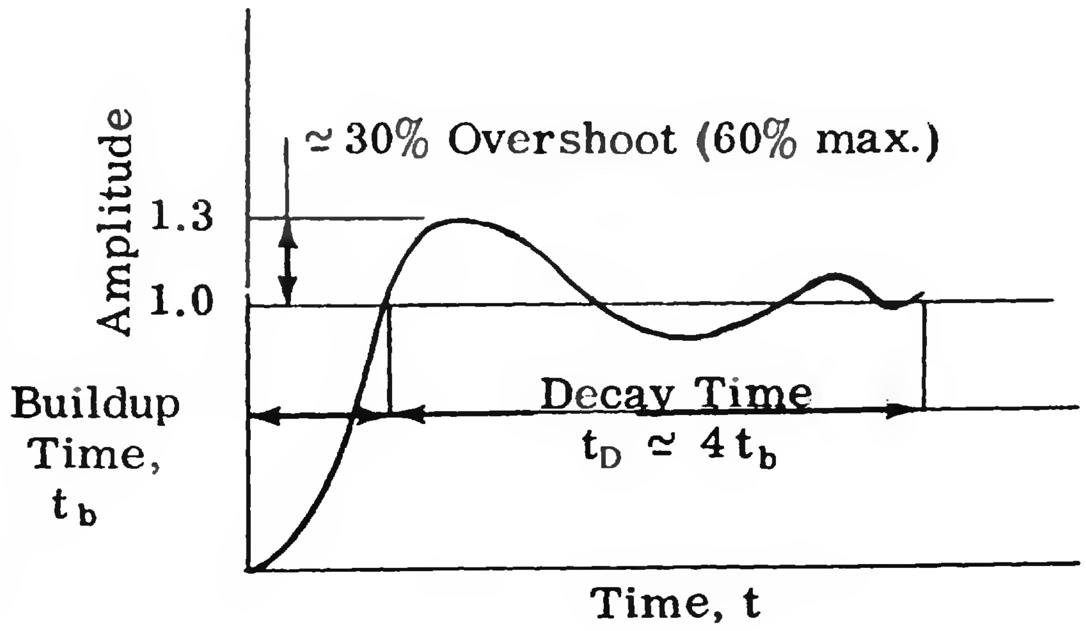
Shelf Life

The in-service capacity of equipment while standing unused.

Shielded Pair

A two-wire electrical transmission line surrounded by a metallic sheath.

FIG. 10.61 CHARACTERISTICS OF A TYPICAL STABLE SERVO



Shock

A suddenly applied force or a sudden change in direction of a motion or a sudden change in velocity of a motion. A shock can be specified in terms of the envelope of spectra for measured shocks (assuming no narrow frequency bands).

Shock, Detached

In supersonic aerodynamics, the flow condition occurring when the shock wave created at the leading edge of a body is not attached to the body but has moved ahead. The shock wave will acquire a smooth, rounded configuration in the immediate vicinity of the leading edge. Condition occurs if the wedge or cone angle exceeds a certain value for a given M; or for any blunt body in a supersonic stream. The flow immediately behind a detached shock is subsonic.

Shock Front (pressure front)

In supersonic aerodynamics, the initial part of the shock wave in which the pressure rises from zero up to its peak value.

The shock front is generally assumed to be infinitely thin and a mathematical discontinuity, but is actually of finite thickness. This front is not in equilibrium; it is a transition region between equilibrium conditions in the air ahead of the shock and the changed gas mixture behind it.

Shock, Ground

(See Ground Shock)

Shock Layer

In supersonic aerodynamics, the region between the shock front and the boundary layer; assumed to be an inviscid flow. Radiation from the shock layer to the nose cone of high speed missiles is one of the causes of skin heating.

Shock Layer Composition

Composition of air is changed by its passage through the shock and into the shock layer where it reaches some sort of thermodynamic equilibrium. Instead of the familiar mixture of about four-fifths nitrogen, one-fifth oxygen and traces of rare gases, the air in the shock layer of a Mach 20 missile is about half atomic nitrogen, one-quarter molecular nitrogen and one-quarter atomic oxygen. Nitric oxide will also be present to some extent.

Shock, Local

A suddenly applied force on an object which does not produce significant displacement except immediately adjacent to the point of application of the force.

Shock Motion

A sudden transient motion with significant relative displacement. In packaging, a sudden change in the velocity of an object, e.g., from rest to motion or vice versa, a condition also termed velocity shock. (See Shock; Velocity Shock)

Shock, Normal

In aerodynamics, a shock wave generated by a flow compression which is perpendicular to the direction of supersonic flow. (See Fig. 10.15, p. 419)

Shock, Oblique

In supersonic aerodynamics, the flow condition occurring when air (or gas) flow is forced to turn in such a direction as to interfere with the flow of air in adjacent stream layers. (See Fig. 10.15, p. 419)

Shock Pulse

The complete description of a shock, i.e., either the force-time relationship of the shock or the displacement-time relationship of the object.

Shock Spectrum

A measure of what a shock does to a complex elastic device. The value at any frequency, f, of the shock spectrum is the maximum acceleration which is experienced by a mass supported by an essentially undamped spring with linear elasticity whose natural frequency is f and which is excited by the shock motion. Velocity or displacement may be used in place of acceleration. Shock spectra may also be specified with stated amounts of damping.

Shock, Swallowed

The condition in a supersonic diffuser when the shock wave has moved inside the intake lip. This is usually an off-design condition. The diffuser or internal drag is increased.

Shock Test

An environmental test intended to subject the test article to a sharp-edged input representative of design requirements.

Characteristics of the test may be varied, depending on the wave shape desired.

Shock Tube

A test device consisting of a controlled-atmosphere tube in which a shock wave is used as a driving force to produce a high Mach number of very short duration (order of milliseconds).

Shock Tunnel

An intermittent blowdown type of wind tunnel with the driving medium being the high-pressure, high-temperature gas pocket produced in the shock tube. By expanding the hot gas pocket through a supersonic nozzle it is possible to extend the useful range of a shock tube to a more accurate simulation of hypersonic flight.

Shock, Velocity

(See Velocity Shock)

Shock Wave

In aerodynamics, an extremely thin wave or layer of gas, generated by the relative supersonic movement of the gas stream and a body, or generated by an explosion. Free stream gas, upon passing through this wave, experiences abrupt and discontinuous changes in pressure, density, velocity, temperature, and entropy. These changes are irreversible owing to some of the pressure energy being lost to heat. Shock waves are commonly called compressive waves, and may be either normal or oblique to the gas-stream direction. The stream upon passing through a normal shock always has its velocity reduced from supersonic to subsonic. In passing through an oblique shock, the velocity is reduced but is still supersonic. In the case of shock waves ahead of blunt bodies of revolution, wherein a normal shock blends into an oblique shock pattern, there will be a sonic line dividing the flow behind the shock wave into regions of subsonic and supersonic flow. In such cases the total stagnation pressure is reduced, while the density, static pressure, and free-stream temperature are increased in the gas stream. (See Fig. 10.17, p. 419)

Shoran (SHOrt RAnge Navigation)

A precision position-fixing system using a pulse transmitter and receiver and two transponder beacons at fixed points. (See Navigation, Hyperbolic)

Shot Effect

The noise produced by the random emission of electrons from a vacuum tube cathode. It is considerably reduced or "smoothed" by space charge effects.

Sideband (s)

(1) The frequency bands on both sides of a carrier frequency within which fall the frequencies of the wave produced by the process of modulation.

(2) The frequency components lying within such bands. In the process of amplitude modulation with a sine-wave carrier, the upper sideband includes the sum (carrier plus modulating) frequencies; the lower sideband includes the difference (carrier minus modulating) frequencies. When only one of these is employed the modulation is said to be single sideband.

Side Lobe

A portion of the radiation from a radar antenna outside the main beam, and usually of substantially smaller intensity. A side lobe is a region between two minima in the pattern.

Sidereal Table

A test device with a servo-driven table which is used to cancel out earth's rotation. The axis of the table is aligned for the particular latitude of location.

Single degree of freedom gyroscope tests are made by connecting the gyroscope sensitive axis to the table servo. At the end of 24 hours, any difference in position from the start is a measure of the gyroscope drift rate, etc.

Sidereal Time

Time measured by the rotation of the earth with respect to the stars. A sidereal day is approximately 8 minutes shorter than solar day.

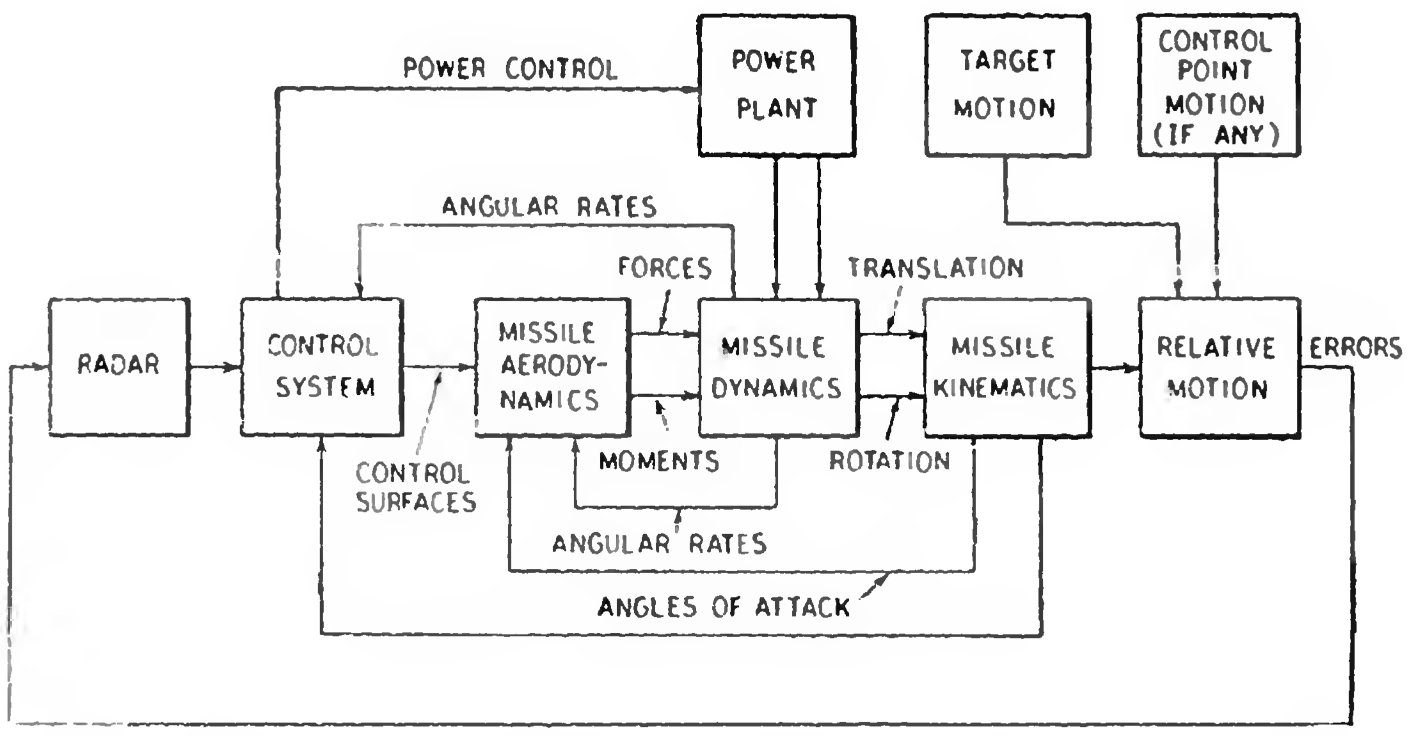
Signal

A detectable physical quantity which conveys useful information; e.g., information relayed from one point in a control system to another.

Signal Conditioner

In instrumentation, a device used to shape or adapt a signal to the requirements of the data transmission link.

FIG. 10.59 BLOCK DIAGRAM DEPICTING SIMULATION OF A MISSILE GUIDANCE SYSTEM



Signal Generator

A test instrument that generates an unmodulated or tone-modulated radio-frequency signal at any frequency needed for aligning or servicing electronic equipment. Also termed an all-wave signal generator, oscillator, or test oscillator.

Signal Strength

A measure of the power output of a radio transmitter at a particular location. Usually expressed as millivolts per meter of effective height of the receiving antenna employed.

Signal-to-Noise (S/N) Ratio

In an electrical system or device for conveying intelligence, the ratio of the value of the signal to that of the noise. This ratio is usually in terms of peak values in the case of impulse noise (see Noise, Impulse) and in terms of the root-mean-square values in the case of the random noise (see Noise, Random). Where there is a possibility of ambiguity, suitable definitions of the signal and noise should be associated with the term; as, for example: peak-signal to peak-noise ratio; root-mean-square signal to root-mean square noise ratio; peak-to-peak signal to peak-to-peak noise ratio, etc.. This ratio is often expressed in decibels. This ratio may be a function of the bandwidth of the transmission system. The term is sometimes used analogously in servomechanisms.

Silver Thaw

After a period of cold weather and below-freezing temperature a mass of warm air passing over the region will cause frost or glaze to form on objects that are still at a low temperature. This condition is known as a silver thaw, and usually lasts only a few hours, as the warm air soon warms all exposed objects above 32°F.

Simplex

A method of operation which permits performing two independent functions alternately as an effective means of simultaneous operation; e.g., alternate firing from several launchers with the same guidance radar. Contrast with Duplex. (See Duplex)

Simulation

A technique for studying a guided missile operation by its simulation in the laboratory. Both physical environment and dynamic behavior can be simulated to varying degrees. Simulation is the imitation of the behavior of the actual missile system by the behavior of some other device. This other device can be made more flexible than the final "hardware"; changes in it can be accomplished with relative ease and at low cost and it can be subjected to performance tests under controlled conditions. In its most basic form the simulator may simply set up the equations governing the behavior of the guided missile. (See Fig. 10.59)

Simulator
Concerning missiles, a device which solves a problem by use of components which obey the same equations as the system being studied. Frequently, an electrical analogue or rotation instead of translation is used for mechanical problems. In general, a simulator is an alternative means of determining the effects of changing each of several design parameters at much less expense than building and testing complete missiles or systems. A simulator which operates only in the yaw (pitch) plane is termed a yaw (or pitch) simulator. The missile is assumed to be completely roll-stabilized and the problem is solved in a single plane.

Single-Base Propellant
(See Propellant, Single-Base)

Single Degree of Freedom (Free) Gyroscope
(See Gyroscope, Single Degree of Freedom)

Single Sampling
Sampling inspection in which a decision to accept or to reject is reached after the inspection of a single sample.

Single-Stage Missile
A rocket missile with a single charge. (See Rocket, Multistage)

Skid Strip
(1) Longitudinal strip on the fuselage of a pilotless aircraft upon which it can be launched and/or landed.
(2) A landing strip on which missiles are recovered.

Skin Friction
(See Drag)

Sky Condition
The state of the cloud cover in the sky. In terms of tenths of sky covered, airways' observers in the United States recognize four sky conditions:
(a) Clear sky is less than 1/10 cover of clouds.
(b) Scattered clouds is 1/10 to 5/10 cover.
(c) Broken clouds is more than 5/10 but not more than 9/10 cover.
(d) Overcast is more than 9/10 cover.

International practice and observations made for synoptic charts in North America recognize 10 states of the sky. They are indicated by code numbers as follows:
0...No clouds
1...Less than 1/10
2...1/10
3...2/10 to 3/10
4...4/10 to 6/10
5...7/10 to 8/10
6...9/10
7...More than 9/10 but with openings
8...10/10
9...Sky obscured by fog, dust, snow, etc.

Slant Range
(See Range, Slant)

Slenderness Ratio
Ratio of the length to diameter of a missile used in connection with aerodynamic studies. Sometines termed fineness ratio.

Slip Flow
An aerodynamic condition where the molecular mean free path is on the order of a fraction of the boundary layer thickness.

Sliver Loss
The portion of a solid propellant rocket charge which is inadvertently unburned. Slivers result from the convergence of the burning surfaces toward a common point and either are discharged with the exhaust gases or left in the rocket case. (Slivers typically represent 3 to 4% of the propellant charge.)

Sloshing
The dynamic motion of a body of propellant in its tank or container.

Slot, Antenna
(See Antenna, Notch)

Slug
A term frequently used by engineers as the unit of mass. The mass of a body in slugs is equal to its weight divided by the acceleration of gravity (= 32.2 ft/sec^2)

Snubber
A device to absorb energy at the end of the stroke of an actuator to avoid excessive inertial loading on the part being moved.

SOFAR (Sound Fixing And Ranging)
In missile applications, an explosive element is used to fix impact location

which is determined from a sound measuring network.

Soft Structure

A structure which is relatively vulnerable to damage from a nuclear explosion, usually located on the surface of the ground. (See Base Hardness; Hard Structure)

Soft Tube

(See Tube, Soft)

Solar Heat

(See Heat Solar)

Solar Radiation

The radiation from the sun, comprising a very wide range of wavelengths from the long infra-red to the short ultra-violet rays, with a maximum intensity in the visible green at about 5000 angstroms. Since the air strongly absorbs the wavelengths toward either end of the spectrum, the radiation received on the surface of the earth is confined largely to the visible and near infra-red regions, with a very small proportion of the ultra-violet. The absorption of the ultra-violet radiation takes place largely in the higher stratosphere, where it probably contributes to the atmospheric ionization (see Ionosphere). The longer infra-red is absorbed mainly by dust and water vapor at lower levels, which accounts for the low temperature of the air at high altitudes. (The estimated maximum at sea level is 360 Btu/sq ft/hr; the average is 105 Btu/sq ft/hr)

Solid Propellant Ramjet

(See Rocket, Ducted Solid Propellant)

Solid Propellant Rocket Engines

Rocket engines whose propellants are chemicals in the solid state before combustion is initiated. (See Rocket Engine) (See Fig. 10.52, p. 479 and 10.16, p. 423)

Solution - Ceramic

A non-brittle, inorganic ceramic coating containing no bonding agent and capable of application at low temperature. (Typical solution ceramics: zirconia, chromia, titania, ceria, etc.)

Sommerfeld Formula

An approximate wave propagation relationship for distances short enough that the earth's curvature may be neglected.

Sonar (SOund Navigation And Ranging)

Equipment employed for underwater detection, ranging, and depth measurement. In a process analogous to that used in radar, sonic or supersonic pulses are transmitted, reflected from an object, and received at the point of transmission. The required time-interval is used as a measure of the distance between the reflecting object and the transmitter. Transducers, which are analogous to radar antennas, are used to propagate and receive the sound energy.

Sonde

In telemetering, the complete airborne telemetering system in the vehicle.

Sonic, Hyper (Hypersonic)

(1) Aerodynamic flow at high supersonic velocities, of the order of $M = 5$ or greater.

(2) Velocities at which time of missile passage is of the same order as relaxation time; i.e., the time for gas molecules to reach equilibrium after sudden change in conditions. In such a domain, gases must be treated as discrete particles rather than a continuum. Measurements of relaxation times of gases are incomplete, but there are indications that Mach numbers of the order of ten must be regarded as hypersonic. Velocities that are not hypersonic at sea level may become so at high altitude, as relaxation times will be longest where densities are relatively low.

Sonic Nozzle

A nozzle converting a high pressure gas to a supersonic flow in which the velocity of gas at the throat is equal to the velocity of sound.

Sonic Speed

The speed of sound. In ambient air, with ratio of specific heats assumed 1.4 and the air following the gas law with temperature in degrees Rankine, the speed of sound is $33.42\sqrt{T}$ miles per hour, or $29.02\sqrt{T}$ knots; with temperature in degrees Kelvin, the speed of sound is $44.84\sqrt{T}$ miles per hour, or $38.94\sqrt{T}$ knots. (See Acoustic Speed) (See Fig. 2.10, p. 42)

Sonic, Sub (subsonic)

Less than the speed of sound or less than a Mach number of one.

Sonic, Super (Supersonic)

Faster than the speed of sound. When supersonic speed is attained by a moving object, no advance information in the form of advance pressure waves can be given to the advancing air, as the body is moving faster than the pressure waves emanating from the body can propagate themselves forward. As a result, shock waves are formed which move with the body and are attached or unattached depending on the conditions.
(See Shock Wave)

Sonic, Tran (Transonic)

The intermediate speed in which the flow patterns change from subsonic flow to supersonic, i.e., from Mach numbers of about 0.8 to 1.2, or vice versa.

Sound (Acoustomotive) Pressure

The instantaneous sound pressure at a point is the total instantaneous pressure at the point minus the static pressure. The unit is the dyne per square centimeter.

The effective sound pressure at a point is the root mean square value of the instantaneous sound pressure over a complete cycle at the point. The unit is the dyne per square centimeter.

The peak sound pressure for any specified time interval is the maximum absolute value of the instantaneous sound pressure in that interval. The unit is the dyne per square centimeter.

The maximum sound pressure for any given cycle is the maximum absolute value of the instantaneous sound pressure during that cycle. The unit is the dyne per square centimeter.

Sounding Rocket

(See Rocket, Sounding)

Source Impedance

The apparent impedance of the signal source. It may or may not be equal to the recommended load impedance. The lower the source impedance, the better the voltage regulation. (Inverse feedback in an audio power amplifier reduces source impedance, resulting in better speaker damping.)

Space

The void between celestial bodies.

Space, Cislunar

The space inside the lunar orbit.

Space, Cis-planetary

Space between the earth's orbit and the orbit of the respective planet; e.g., cis-Martian space = space between earth and Mars; cis-Venusian space = space between earth and Venus.

Space, Extra-planetary

Space beyond the particular planetary orbit as seen from the sun; e.g., extra-trans-Plutonian space.

Space Flight

The science of extra-terrestrial flight of unmanned vehicles. Contrast with Space Travel. (See Astronautics; Cosmonautics)

Space, Galactic

Interstellar space in general within the respective galactic system.

Space, Intergalactic

Space between galaxies.

Space, Interplanetary

The space between the planets.

Space, Intra-planetary

Space between the sun and the orbit of the respective planet; e.g., intra-Mercurial space.

Space, Interstellar

Space between suns or solar systems.

Space, Lunar

The space inside the lunar activity sphere with respect to the earth.

Space, Planetary

The region at close vicinity to the respective planet, in the same sense as defined for terrestrial space.

Space, Terrestrial

The region roughly between 200 and 3,500 miles (1 earth radius) altitude dominated practically exclusively by terrestrial gravitational and geo-physical phenomena.

Space, Translunar

The space between the distance of the lunar orbit and the limit of the earth's activity sphere with respect to the sun.

Space, Transplanetary

Space beyond the orbit of the particular planetary orbit as seen from the

earth; e.g., Mercury's orbit lies in the trans-Venusian space.

Space Travel

The science of extra-terrestrial flight of manned vehicles. Contrast with Space Flight. (See Astronautics; Cosmonautics)

Space Vehicle

(1) An artificial body operating essentially or exclusively outside the earth's atmosphere; technical requirements and mission are determined by space conditions.
(2) Instrumental: A pilotless space vehicle.
(3) Manned: Occupied for a comparatively short time (also: piloted).
(4) Inhabited: Occupied for days or longer.

Spallation

(See Fission, Nuclear)

Special List of Equipment (SLOE)

A military publication that establishes temporary equipment allowances. It also may be used to authorize nonstandard equipment on a continuing basis.

Specification, Detail

A detail description of a particular model missile prepared by the designer which cites all specific design and construction criteria.

Specification, Model

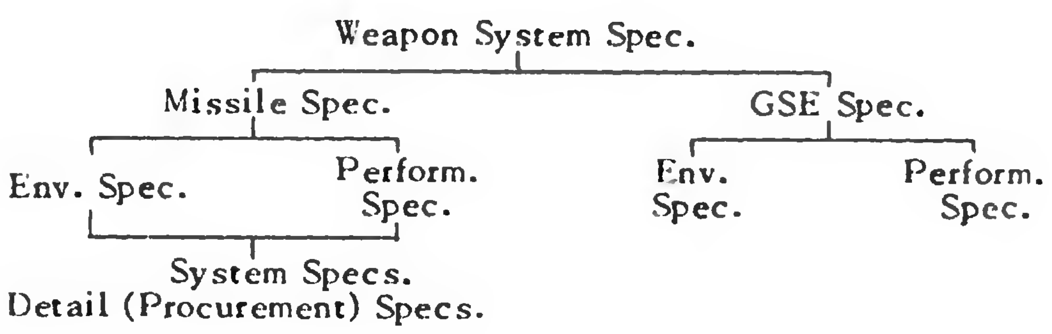
(See Model Specification)

Specification, Performance

(See Performance Specification)

Specification Tree (or chart)

A scheme for categorizing the specifications required for a weapon system to show their interrelation; e.g.,



Specific Fuel Consumption

(1) In thermal engines, the mass of fuel used relative to an appropriate unit of output; jet engines usually are rated in pounds (fuel) per pounds (thrust) per hour, while reciprocating engines are rated in pounds (fuel) per horsepower-hour.

$$SFC = \frac{\text{Fuel flow in lb/hr}}{\text{lb thrust}}$$

(2) The reciprocal of specific impulse; pounds per pound second. Sometimes termed the Performance Index.

Specific Impulse (I_{sp})

In rocketry, a parameter indicative of efficiency: a property of the propellant combination and the mixture ratio. Specific impulse is equal to pounds of thrust developed per pound of propellants consumed (fuel plus oxidizer) per second, or the ratio of thrust to propellant mass flow. (See Specific Impulse, Ideal; Total Impulse) (See Sec. 7.4, p. 287 7.5, p. 289, 7.6, p. 296 and Fig. 7.6.5, p. 301)

Specific Impulse, Air

A figure of merit for a jet engine propelling a guided missile; expressed as pounds of thrust per pound of fuel consumed each second; the ratio of the critical stream thrust (at $M = 1$) to the mass flow. (See Eq. 7.3.2, p. 285)

Specific Impulse, Fuel

In rocketry, the thrust developed by burning one pound of fuel in one second, or the ratio of the thrust to the fuel mass flow.

Specific Impulse, Ideal or Theoretical (I'_{sp})

The maximum realizable impulse obtainable from a given combination of propellants; calculated from thermochemical relations. The difference between the ideal and measured specific impulse (I_{sp}) is due to heat losses, incomplete combustion of propellants, flow losses and variations in back pressure. I'_{sp} usually ranges from 0.93 to 0.98 of I_{sp}. (See Eq. 7.4.11, p. 288)

Specific Impulse, Over-all

In rocketry, the impulse per unit total weight of system. (See Eq. 7.5.3, p. 289)

Specific Speed

A design parameter used in high-speed rotating pump calculations.

$$N_s = N\frac{Q^{1/2}}{h^{3/4}} \quad \text{rpm}$$

where N = speed, rpm
Q = pump output, gpm
h_{sv} = rise in pump head, inlet to discharge, ft.

Specific Thrust

The ratio between the thrust of a jet reaction motor and the total propellant flow rate producing the thrust.

SPHEREDOP

A DOVAP type measuring system employing a stable, airborne oscillator. In contrast to DOVAP it eliminates the reference transmitter to the missile. (See DOVAP)

Spherical-Trigonometric Computer

(See Computer, Spherical-Trigonometric)

Spike Diffuser

(See Diffuser, Oswatitsch)

Spillover

That portion of the air in the streamtube which flows to the side of a ramjet intake rather than through the intake. This takes place under conditions of detached shock. Under conditions of attached or swallowed shock, there is no spillover. (See Fig. 10.15, p. 419)

Spin Stabilization

A technique for stabilizing a missile during boost, midcourse or terminal phases in which a slow spin is used to eliminate dispersion due to misalignments. Appropriate discrimination of guidance intelligence is required to insure proper control in each plane.

Spontaneous Fission

(See Fission, Nuclear)

Spot Jamming

(See Jamming, Spot)

Spray Dome

The mound or column of broken water and spray thrown up over the point of burst of an underwater nuclear explosion be reflection of the blast wave at the surface.

Spurious Signal

Any unwanted signal, either generated in the equipment itself or having external origin (noise).

Squall

A sudden, strong wind which may or may not be accompanied by a wind shift. Rain and snow squalls are showers accompanied by strong winds.

Squall Line

Thunderstorms, rain showers or squalls, and snow showers or squalls often appear in a long line sometines reaching hundreds of miles but only one squall in depth. Such lines of squalls normally move perpendicular to their leading edge.

Square-law Detector

A vacuum-tube circuit in which the output signal current strength is proportional to the square of the radio-frequency input voltage. The demodulation depends on curvature or non-linearity of the characteristic, rather than on rectification, to produce the distortion or asymmetrical form of the modulated wave necessary for detection. The largest distortion term is the second power, or square term.

Square Wave

A wave which alternately assumes two fixed values for equal lengths of time, the time of transition being negligible in comparison with the duration of each fixed value.

A square wave requires a considerable number of sine-function frequencies to express it in a Fourier series. These components are not mere mathematical functions but are true electrical components in the case of an electric wave. They may be separated and examined by means of proper filter circuits. Since a square wave will contain a long series of frequencies, it may be used for determining rapidly the frequency response, of a piece of equipment by applying the wave to the input and noting the distortion of the output wave. The distortion is due to certain frequencies of the original wave being attenuated or amplified out of proportion in passing through the circuit. Thus the necessity of making a laborious series of tests at various frequencies using sine waves is avoided. When an operator is properly trained in interpreting the results of such testing, it offers a rapid means of checking amplifiers, networks, etc.. These square

waves may be generated by a variety of electronic circuits.

Squib

An electrical-pyrotechnic device used to ignite an explosive material, a primer or igniter.

Squib Switch

A type of switch with an explosive element switch.

Squint Angle

A geometrical characteristic of an antenna defined as the angle between the main lobe of the antenna pattern and the spin axis of gyroscope used to stabilize the antenna.

Stable Element (Stable Table; 3 Axis Table; Stable Platform)

A gyroscope-stabilized platform or a stable free gyroscope used as a reference system for guidance and control purposes. (The platform characteristics usually include: minimum deadzone, high gimbal frequency response, good linearity, high signal resolution and large angular range.) (See Gyroscope, Stabilized Platform)(See Fig. 10.34, p. 457)

Stable Servo

(See Servo, Stable)

Stability

That attribute of a system which enables it to develop restoring forces between the elements thereof equal to or greater than the disturbing forces so as to reestablish a state of equilibrium between the elements.

Stability (and Control) Coefficients

A set of coefficients which assume linear aerodynamic coefficients in the missile equations of motion in a plane of maneuver at a constant speed and which are useful in defining certain characteristics of a missile, e.g., weathercock frequency, damping, stability and control, etc.

Stability, Arrow

(See Weathercock Stability)

Stability Derivatives

Equations of motion for a missile associated with stability and control and based on linear aerodynamic coefficients. The lateral stability derivatives relate to:

Directional stability - yawing motion due to yaw
Rolling moment due to yaw
Damping in yaw
Damping in roll
Rolling moment due to yawing velocity
Yawing moment due to rolling velocity

Similar derivatives exist for the pitch plane. (See Sec. 5, p. 209)

Stability, Directional

Stability of a missile with reference to disturbances about its normal axis, i.e., disturbances which tend to cause yawing.

Stability, Dynamic

The characteristic motion of a missile as it returns to its steady-state condition after a disturbance has produced an unbalanced moment. The natural frequency of this "weathercock" oscillation and the time-to-damp-to-half-amplitude are the usual criteria for dynamic stability.

Stability, Effective Static

In aerodynamics, the slope of the moment coefficient versus normal force coefficient curve.

Stability, Inherent

Stability of a missile owing solely to the disposition and arrangement of its fixed parts: i.e., that property which causes it, when disturbed, to return to its normal attitude of flight without the use of the control system or the interposition of any mechanical device.

Stability, Lateral

Stability of a missile with reference to disturbance about its longitudinal axis: i.e., disturbances involving rolling or sideslipping. The term lateral stability is sometimes used to include directional and lateral stability, since these cannot be entirely separated in flight.

Stability, Longitudinal

Stability of a missile with reference to disturbances in its plane of symmetry, i.e., disturbances involving pitching and variation of the longitudinal and normal velocities.

Stability, Static

That property of a missile which causes it, when its state of steady flight

is disturbed, to develop forces and moments tending to restore its original condition.

The amount of static stability is usually measured in terms of missile body diameters, i.e., so many body diameters (distance) between the center of pressure and the center of gravity.

Stabilized Platform

(See Gyroscope, Stabilized Platform)

Stage

(1) All the components in a circuit containing one or more vacuum tubes having one single input and one output receiving power from a preceding stage or device, and the output feeding power to a succeeding stage or device.

(2) In a missile consisting of several sections which are progressively jettisoned or staged during the flight, the independent sections, when containing a power plant, are termed stages. Note that an unpowered payload (e.g., reentry body) is not classified as a stage.

Staging

Act of jettisoning, at a predetermined flight time or trajectory point, certain missile components (engines, tanks, boosters, staging equipment and associated equipment) that are no longer needed.

Stagnation Temperature

The temperature of air which has been brought to rest from a given velocity or Mach number.

Stagnation Region

In high speed missiles, a region at the front of the nose cone where there is negligible velocity of the air flow along the axis; the air is at stagnation temperature.

Standard Atmosphere

A model or standardized set of characteristics of a hypothetical earth's atmosphere as a function of altitude. A number of Standard Atmospheres have been proposed and used (NACA, Rand Corporation, ICAO, etc.) but the Abbreviated Tables of the ARDC Model Atmosphere is the preferred model for current use. (See Fig. 2.4, p. 29)

Standard Day

A day whose temperature and pressure vs altitude characteristics are standardized. A number of standard days are in use: NACA, Navy BuAer, etc.

Polar Tropical	Standard days used for design for dependent flight conditions.
Cold Hot	Standard days used for design for non-time dependent conditions. These characteristics represent statistical envelopes and cannot exist meterologically.

(See Fig. 3.1, p.50)

Standard Deviation (σ)

A measure of dispersion. To obtain σ, the squares of the deviations (x) of the individual values from the average are added and divided by the number (N) of data. Also termed root mean square error; standard dispersion. (See Fig. 3.13, p. 92)

Standard Dispersion

(See Standard Deviation)

Standard Error

(See Standard Deviation)

Standard Operation Procedure (SOP)

A set of instructions covering those features of operations that lend themselves to a definite or standardized procedure without loss of effectiveness. The procedure is applicable unless prescribed otherwise in a particular case. Thus, the flexibility necessary in special situations is retained.

Standing Wave Ratio (SWR)

In a radio frequency transmission line the quantity describing the variation of the rms voltage.

$$\text{swr} = \frac{E_{max}}{E_{min}}$$

When measurements are made which are proportional to the square of the voltage, the power standing wave ratio is obtained.

Star Brightness

A first magnitude star gives about 100 times as much light as a sixth magnitude star. The fifth root of 100 is 2.512, and this is used as the standard magnitude ratio. A first magnitude star is 2.512 times as bright as a second magnitude star, and so on. Since a difference of 0.1 is the smallest change in magnitude that

can be detected by the human eye, tabulated magnitudes are usually given to one decimal place. These magnitudes are apparent magnitudes of brightness in the optical wave length portion of the spectrum.

Star Grain
A solid rocket propellant configuration with an internal star-shaped characteristic cross section. (See Fig. 10.16, p. 423)

Star Tracking (Automatic Celestial Navigation)
A celestial navigation technique used for guiding long-range surface-to-surface missiles. The system consists of a device to measure attitude of the stars, an accurate clock and a storage device to include information on charts and star tables.

Static Behavior
The behavior of a control system, or an individual unit, under fixed conditions (as contrasted to dynamic behavior which refers to behavior under changing conditions).

Static Stability
(See Stability, Static)

Static Test
(1) A structural test used to establish degree of conformance to the design.
(2) A test of a missile propulsion system while the engine or missile is restrained. This is more properly termed a captive test.

Static Thrust
(See Thrust, Static)

Stay Time
In liquid rocket engine usage the average value of the time spent by each gas molecule or atom within the chamber volume.

Steady State
(1) A physical system is said to be in a steady state if the various quantities describing the system are either independent of time or are periodic functions of time. Thus an alternating current circuit is in a steady state after all transient effects of a disturbance have disappeared.
(2) A condition of dynamic balance in combustion, as in an equilibrium reaction, where the concentration of each of the reactants remains constant. In such cases the loss of reactants to form products just balances the formation of reactants from the products in the reverse reaction.
(3) In aerodynamics, the state of static stability of the missile; no transients are present.

Steady-State Oscillation
A condition in a dynamic system in which the energy input and damping are so in balance that the oscillation neither diverges nor damps out.

Stereographic Projection
In cartography, a technique for portraying the earth's surfaces; the projecting plane is perpendicular to the axis of the earth and points on the earth are projected by straight lines from the opposite pole.

Stiction
Static friction.

Stiffness/Weight Ratio
In structural engineering, the ratio of the modulus of elasticity to weight. (See Fig. 4.9, p. 121)

Stochastic
The stochastic variable is dependent on the random variable, e.g., a random choice of ξ will define some value of X. The stochastic variable is usually the quantity measured experimentally.

Stockpile
A reserve stock of material, equipment, raw material, or other supplies.

Stoichiometric (mixture)
The components involved in a burning process which are present in exactly the quantities needed for reaction without an excess of any component.

Storage
A missile enviornmental phase starting with delivery to a depot or other permanent storage area and ending with movement to a dock for transportation. Preventive maintenance is minimized during this period by protective design.

Storage, Ready
(See Ready Storage)

Stowage
A missile environmental phase covering its temporary storage, usually aboard

a ship. Stowage is ordinarily and arbitrarily considered not to exceed a 6 month period.

Strain

The deformation of a body resulting from a stress; measured by the ratio of the change to the total value of the dimension in which the change occurred.

Strategic Information

Unclassified scientific, technical, industrial or economic (non-statistical) information, the indiscriminate distribution of which may be inimical to the defense interests of the United States.

Strategic Missile (SM)

A missile carrying a nuclear warhead used for long-range bombardment.

Strategic Missile Squadron

The smallest Air Force strategic missile organization possessing an administrative capability. It consists of from three to six flights and appropriate command and administrative elements.

Strategic Missile Support Squadron

An Air Force organization assigned to the support base. It provides support for all missile units in the launch base area.

Strategic Missile Wing

An Air Force organization composed of one Strategic Missile Support Sauadron and two or more Strategic Missile Squadrons.

Strategy

The art of utilizing national resources for best prosecution of a war; pertains to the preparations for battles or campaigns and the exploitation of their outcome.

Stratosphere

That layer of the atmosphere beginning at the tropopause and extending from approximately 10 miles to 20 miles altitude. The stratosphere is between the troposphere and the mesosphere. (See Fig. 10.5, p. 400)

Stream Thrust

The sum of the aerodynamic pressure force transmitted across a specified cross section and the time rate of momentum flow across the same cross section.

Strength-Weight Criterion

A design criterion which gives the lightest weight member for a given geometry and loading condition: e.g., in high-temperature applications, a material based on a strength-weight-temperature criterion.

Stress

The force producing or tending to produce deformation in a body; measured by the force applied per unit area.

Stress Analysis Report

A standard report used in missile design. It includes shear and moment diagrams based on loading conditions presented in the Loads Report, design criteria, design allowables, margins of safety, detail stress analysis and temperature corrections.

Strip Chart Recorder

Indicates and records any slowly varying function in real time. Typical frequency response is less than 50 cps.

Structural Density

The weight of a structural material relative to its enclosed volume.

Structural Filter

An electronic or mechanical device designed to filter or attenuate a particular frequency (or frequencies) of the missile airframe of other structure. It is usually required to notch out the first free-free bending mode of the airframe to avoid coupling with the rate gyros of the control system. Such designs frequently take the form of a band pass or a high cutoff filter. (Such filters seldom need to attentuate the signal from the control system sensing element by more than 12 db per octave.)

Structural Loads

Aerodynamic loads, modified by the inertia loads of a missile's component parts during steady-state or dynamic conditions.

Structural Test Report

A standard report used in missile design. It includes detail test procedures, loads and load distribution for the static and dynamic tests to be performed to confirm the basic design, and detail test results.

Subcritical Operation

A condition of ramjet operation, if the Mach number M decreases during subcritical operation, more air is "spilled over" the intake because of the decreased pressure rise achievable by the diffusion system. As a consequence, the gross thrust decreases still more and if the decrease in Mach number cannot be halted, the ramjet engine finally becomes unable to overcome the drag of the missile it is propelling.

Subharmonic

A component of a periodic quantity having a frequency which is an integral submultiple of the basic frequency.

Note: The term subharmonic is generally applied in the case of a driven system whose vibration has frequency components of lower frequency than the driving frequency.

Subminiaturization

Usually applied to airborne equipment; a technique of reducing size and weight. The next reduction after miniaturization. Typical characteristics of subminiaturized packages: high density, special heat dissipation provisions, plug-in design, modulized, printed circuitry, detail attention to layout. (See Miniaturization)

Sub-Missile

One of several smaller missiles carried and released by a larger missile, especially in a warhead.

Subsonic

(See Sonic, Sub)

Subsonic Diffuser

(See Diffuser, Subsonic)

Subsonic Leading Edge

A condition of supersonic flow over an airfoil wherein the leading edge angle, as measured from the centerline, is less than that of the Mach angle μ, defined as:

$$\mu = \sin^{-1}\left(\frac{1}{M}\right)$$

The leading edge is said to lie within or behind the Mach angle.

Subsonic Nozzle

(See Nozzle, Subsonic)

Subsonic Region

A region in which the fluid flow is subsonic in contrast with supersonic; e.g., where the flow with respect to the surface of a nose cone is subsonic.

Subsonic Trailing Edge

A condition of supersonic flow over an airfoil wherein the angle between the trailing edge and the centerline is less than that of the Mach angle.

Sub-Surface Launch Structure

An underground launcher.

Subsystem

A major functional assembly within a system.

Subsystem, Major

Large functional division of a weapon system, e.g., airframe, propulsion, guidance, and range safety.

Suction Specific Speed

A design parameter used in high speed rotating pump calculations.

$$N_{sv} = N \frac{Q^{1/2}}{h_{sv}^{3/4}}$$

where N = speed, rpm
Q = pump output, gpm
h_{sv} = net positive suction head, ft.

Superaerodynamics

The study of the dynamics of gases at very high altitudes or extremely low densities.

Supercritical Operation

A condition of ramjet operation wherein the heat released by the burner causes the back pressure on the exit section of the diffuser to become too small for maintaining the normal shock at the inlet. The excess pressure (or energy) in the air must be dissipated within the diffusion system by some form of discontinuous process, and such a process is possible only in a supersonic flow. Consequently, the air flows into the subsonic diffuser with supersonic velocities. Since the flow passage is diverging, the flow area is increasing, and the Mach number for the air likewise increases. The excess energy is finally dissipated by a strong shock wave forming in the diverging portion of the subsonic diffuser.

Superheterodyne Receiver

A radio receiver designed to obtain superior fidelity characteristics. The

system includes a radio frequency amplifier, local oscillator, crystal mixer, intermediate frequency amplifier, second detector, video amplifier, and cathode follower output.

Supersonic
(See Sonic, Super)

Supersonic Diffuser
(See Diffuser, Supersonic)

Supersonic Nozzle
(See Nozzle, Supersonic)

Supersonic Region
A region in which the fluid is supersonic as contrasted to subsonic, e.g., where the flow is supersonic with respect to a missile surface and remains that way downstream.

Support Base
The place from which logistics support is provided for a group of launch complexes and their control center.

Surface Burst
A nuclear explosion at the surface of land or water or at a height above the surface less than the maximum fireball radius.

Surface-to-Air Missile
(See Missile, Ground-to-Air; Missile, Guided; Model Designation)

Surface-to-Surface Missile
(See Missile, Ground-to-Ground; Missile, Guided; Model Designation)

Surface-to-Underwater Missile
(See Missile, Ground-to-Ground; Model Designation)

Survival Probability
In operations research, the chance that a target will survive a given operation.

Sustainer
A propulsion system, which travels with, and does not separate from, the missile. Usually applied to solid propellant rocket motors when used as the principal propulsion system as distinguished from an auxiliary motor, or booster. Sometimes applied to any missile stage except the booster.

Sweat (Transpiration) Cooling
A technique for cooling combustion chambers or aerodynamically heated surfaces by forcing a coolant through a porous wall. Film cooling at the interface results.

Sweepback
The acute angle between a line perpendicular to the plane of symmetry and the plan projection of a reference line on a missile wing.

Symbolic Logic (Mathematical Logic)
A mode of developing and representing logical principles through the use of symbols for classes, propositions, etc., rather than a theory of logic. It provides an exact canon for deduction in general and is usually developed by rigorous deduction from postulates and definitions.

Synchro
The universal term applied to any of the various synchronous devices as the Selsyn, Autosyn, motor torque generator, mag-slip, and Siemans. Theoretically a synchro device is treated as a salient-pole, bipolar, AC - excited synchronous machine. The standard signal and control synchro has a two-pole, single-phase, rotor field and a Y-wound, single-phase, variable-voltage stator. The transmitter of the synchro, whose rotor is geared to (or otherwise linked with) mechanical equipment whose motion is to be measured, is also termed a generator, synchro-generator, or Selsyn-motor. The synchro has a rotor that is free to rotate, and is damped to prevent excessive oscillation before coming into correspondence with the rotor of the transmitter.

Synergy
A term coined by Oberth to describe the compromise between the most efficient ascent of an escape vehicle when fired horizontally due east, and the avoidance of air resistance, etc.: e.g., the ideal velocity for a synergic ascent is between 37,800 ft. per sec. and 39,400 ft. per sec. which would save 2300 to 6900 ft. per sec. in energy requirements for escape from the atmosphere.

Synoptic
A chart, such as the ordinary weather map, which shows the distribution of meteorological conditions over an area at a given moment.

System
A group of equipment or sub-assemblies especailly integrated to perform a specific function or functions: e.g., a fire control system which includes the missile, GSE, and ancillary guidance equipment; a division of a missile such as a propulsion system.

System, Attitude Control
(See Automatic Pilot)

System Phasing
Adjusting the acquisition of all components to the longest lead time item, and identifying and scheduling all action necessary to achieve a complete system by a programmed date.

System Reliability
The probability that a system will perform its specified task under stated tactical and environmental conditions. This will include accuracy.

Systems Engineering
An engineering approach which organizes men, materials, and technologies for the purpose of developing an optimum device

Systems engineering covers two basic fields that are generally considered to be relatively independent, technical and administrative coordination. The technical aspect of systems engineering deals with the compatibility of the physical components which go to make up a weapons system; it is the effort which insures that each component fits physically, dynamically, and functionally with other components of the system. The administrative function deals with the problems of manpower utilization, procurement, scheduling, cost control, reporting, etc.

T

t-time, T-Time
Time measured from the first motion, or lift-off, of a missile when it is being launched. Only (+) t-times are used. Prior events are timed in (-) x-time and (+) x-time.

T/A
Table of Allowance

TACAN (TACtical Air Navigation)
A system whereby the distance and bearing of an airplane from a fixed point is indicated on dials, or other devices within the airplane. Ultra-high-frequency signals pass between airplane and ground station, the operator in the airplane tuning to the station frequency. Because of the line-of-sight nature of these high-frequency waves, the effective range is limited by earth curvature, and many ground stations are required in a complete system.

TM
Tactical Missile. A guided missile used in tactical operations.

T/O
Table of Organization.

TTE
Tentative Table of Equipment.

Tactical Doctrine
Standardized employment of weapons based on prior experience; doctrine is normally prescribed for field forces in suitable publications.

Tactics
The art of employing field forces and their material for best prosecution of a battle; pertains to military operations ensuing after contact with an enemy.

Tail Control
A method of missile control surfaces at the rear of the body. Lateral forces are obtained from fixed lifting surfaces mounted on the body generally near the midsection, the entire configuration being deflected to an angle of attack by the tail control surfaces. A wingless tail control design may be achieved by omitting the wings and obtaining the desired lift from angle of attack of the body.

Tail Grab (Missile Retainer)
A device employed to secure a missile to its launcher by "grabbing" or holding the missile tail section strong points to prevent missile motion until the desired thrust level is reached. Release is accomplished at the instant of launch.

Tailless (Elevon) Control
A method of missile control using but one set of surfaces with control flaps located at the trailing edge, the fixed surface providing the lift and the moveable surfaces the necessary lateral and longitudinal control.

Tandem Missile
A fore and aft configuration used in boosted missiles, long range ballistic

missiles, satellite vehicles, etc. Stages are stacked together in series and are discarded or staged at burnout of the propellant for each stage.

Tank Circuit

An inductor and a capacitor in a parallel connected resonant circuit. Since such a circuit has the ability to store energy for a short period of time, it acts as a reservoir or tank. Hence the term tank circuit.

Target

An enemy vehicle, installation, facility, or other materiel or personnel against which attacks are to be made.

Target Acquisition

First appearance in a radar or other search system of recognizable intelligence of a target. Also termed detection.

Target Complex

A group of targets having a common strategical or tactical interest.

Target Discrimination

That quality of a guidance system which enables it to distinguish a target from its background or between two or more targets in close proximity.

Target Drone

A pilotless aircraft used exclusively as a target for anti-aircraft weapons.

Target Fade

A decrease or loss of signal due to interference or other phenomena. (Tracking loops usually include memory circuitry to cause the radar to continue to track at the same rate during this period.)

Target Identification

The act of determining the nature of a target and whether it is friend or foe. (See Identification, Friend or Foe)

Target Noise

Statistical reflections of a transmitted radar signal caused by the target having a number of reflecting elements randomly oriented in space.

Target Profile Area

A sectional area of a target, as it affects detection, radar reflection and vulnerability.

Target, Radar

Any radio frequency reflecting object of particular interest in the path of a radar beam.

Target Scintillation

The apparent random movement of a target's center of reflectivity during the course of a tracking operation.

Target Vulnerability

The resistance to destruction which a target possesses with respect to a weapon which is intended to destroy it.

Target Weight

(See Weight Bogey)

Technical Direction

The act of directing by a central agency of a weapon system development being done by a number of independent industrial/university groups. The concept is one of a systems engineering group giving broad technical direction to the program as a whole and detail direction where required to further the effort.

Technical Test Control

The specialized or professional guidance and direction exercised with respect to the Missile Test Center aspect of tests and includes the authority to schedule, alter or stop individual tests in accordance with dictates of safety, undue interference to other tests, technical feasibility of the range to accept any test and limitations imposed by available test resources.

Technical Test Direction

The determination and execution of test programs in accordance with directives or contractual authority of the sponsoring service, including the determination of technical validity of test objectives, the formulation of general test programs and detailed test plans, the preparation of articles to be tested, and the prosecution of tests and evaluation of test data, the reporting of test results, and the reorientation of the test program and plans based on these data.

Telemeter Band

A subcarrier band (18 in the standard FM/FM telemetering system) which is used to modulate a carrier. The center frequencies of the 18 bands are separated by the ratio of 1.3:1 (except between 14.5 and 22 kc.).

(Contrast with Telemeter Channel)
(See Fig. 6.24, p. 258)

Telemeter Channel

An information channel which may be continuous or sampled. Multiple channels may be handled on one telemetering band by multiplexing.

Telemetering

Transmission of a measurement over long distances, usually by radio means. A receiving instrument converts the transmitted electrical signals into units of data which can be translated by data reduction into appropriate units. (See Telemetering, FM/FM; Telemetering, Pulse Duration Modulation, p. 258)

Telemetering, FM/FM

A standard telemetering system used at all missile development centers in the United States. The 18 subcarrier bands are frequency modulated and the RF carrier is also frequency modulated; hence the term FM/FM. (See Fig. 10.62 and Sec. 6, p. 258)

Telemetering Pickup

A device used to measure and convert data to be telemetered into a form suitable for modulation of the telemetering link. Pickups are used to measure strain, pressure, voltage, vibration, acceleration, fuel flow, position, counters (cosmic ray), temperature, etc. Variable voltage, resistance, reluctance, capacitance or inductance can be used. Sometimes termed end organ, end instrument, or transducer.

Telemetering, Pulse Duration Modulation (PDM)

A system used where time division multiplexing is acceptable. A large number of channels of information can be handled but the frequency response is reduced in comparison to the subcarrier bands of the FM/FM system. The RF carrier may be modulated by either frequency modulation (PDM/FM) or phase modulation (PDM/PM).

Telemetering, Pulse Width Modulation (PWM)

In PWM telemetering systems, a voltage-generating end instrument is sampled briefly to determine its instantaneous level. This level is converted, by appropriate circuitry, into a pulse whose duration is a measure of the original voltage level. Sometimes termed Pulse Duration Modulation (PDM). (See Fig. 6.27, p. 260)

Telemetering System

The complete measuring, transmitting, and receiving apparatus for remotely indicating, recording and/or integrating information. (See Fig. 10.62)

Telemetry

The process of transferring information from one point to another remote point, usually electromagnetically.

Telescopic Photographic Recorder (TPR)

A transportable, single telescope recording field instrument for tracking missiles. Provides velocity, acceleration, spin rate, attitude, and position. Angular data and correlated time are film recorded.

Temperature Recovery Factor

In aerodynamics, the ratio of actual temperature rise in the boundary layer to the adiabatic temperature rise.

Terminal Phase

(1) A guidance phase covering that portion of a missile's trajectory from the end of midcourse guidance to the impact with the target.
(2) For ballistic missiles, the terminal phase is that part of trajectory from reentry to impact.

Ternary Fission

(See Fission, Nuclear)

Terrestrial Reference Guidance

(See Guidance, Terrestrial Reference)

Terrestrial Space

(See Space, Terrestrial)

Test

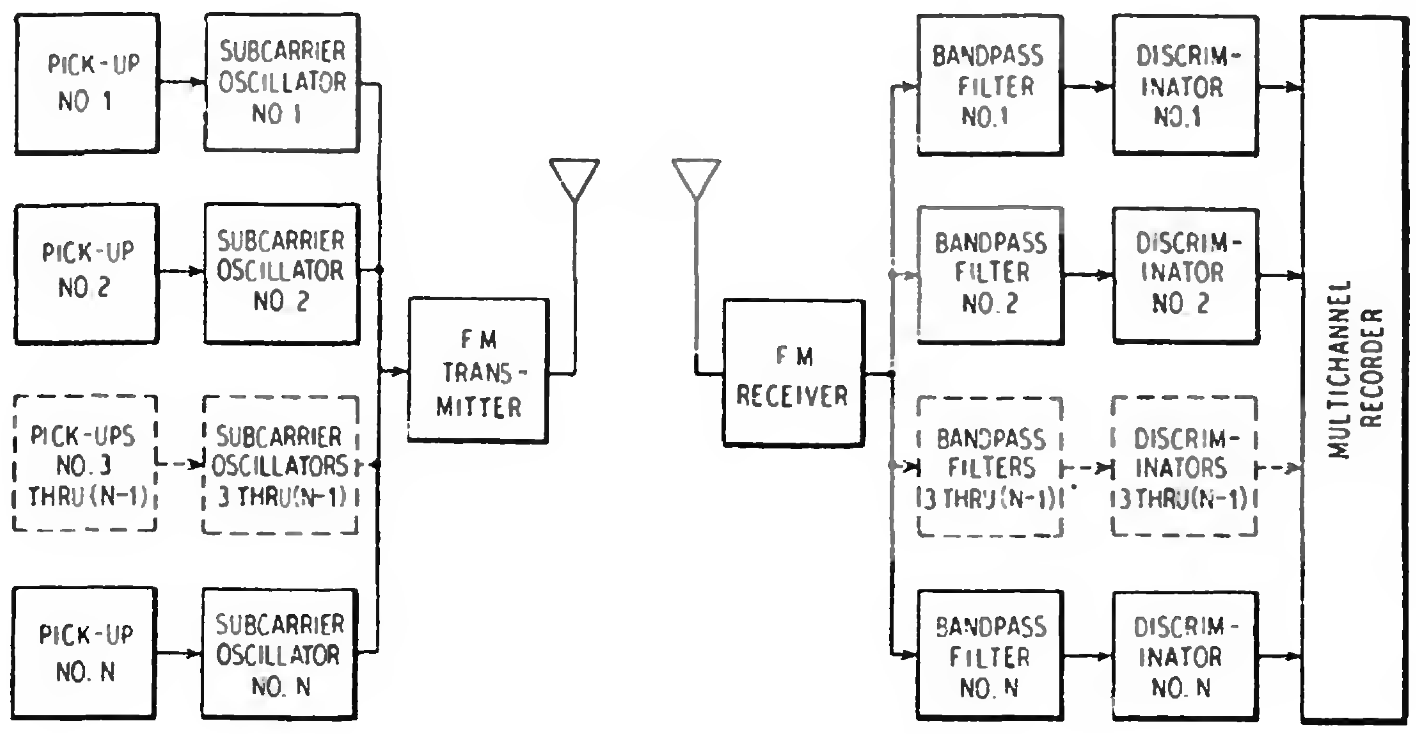
The technique and methods employed to determine compliance of design and performance with requirements.

Test-Failure Load

For a structural member the smallest load obtained by applying any of the following criteria to the results of static load tests:

(a) The load which produces a permanent set (strain) of X inches per inch at a critical point in a primary structural

FIG. 10.62 SIMPLIFIED FM/FM TELEMETERING SYSTEM



member. (The value for X is selected to suit the particular material, structure and load situation.)

(b) The load which produces a total deformation (either permanent or elastic) established as a limit by performance requirements.

(c) The load which produces collapse or buckling; applicable if (a) or (b) does not apply. A factor-of-safety, depending on judgement, and varying between one and one a half, must be applied to allow for unknown or variable factors.

Tests, Evaluation

Tests conducted by a developing agency comprising examinations, investigations, or other observations necessary to determine the technical adequacy of the material undergoing test. Pilot or experimental models are subjected to these tests at the various laboratories and proving grounds prior to initiation of procurement of a production model.

Test Point, Major

A test point used to identify an overall function of a missile subsystem.

Test Stand

A device for holding a rocket motor or missile in position for captive or flight test.

Theodolite

An optical instrument for measuring horizontal and/or vertical angles with precision.

Thermal Jet Engine (Air-Breathing Engine)

A jet propulsion engine which uses air to support combustion and for the creation of a high speed jet stream. (See Jet Engines; Propulsion, Jet; Sec. 7, p. 273)

Thermal Jet Engines, Types of

Ramjet, Pulsejet, Turbojet (See Ramjet; Pulsejet; Turbojet; Sec. 7, p. 273)

Thermal Radiation

Radiation emitted by a body as a result of its high temperature.

Thermal Reactor

(See Reactor, Thermal)

Thermistor (THERMal ResISTOR)

A partial conductor or resistor whose resistance varies with temperature in a definite desired manner. Used in circuits to compensate for temperature variations in other parts, or to measure temperatures, or as a nonlinear circuit element.

Thermojet (Thermal Jet Engine)

An air-duct type engine in which thrust is obtained by scooping air from the surrounding atmosphere, compression heating by combustion, and discharging the exhaust gases at high velocity. (See Jet Propulsion; Sec. 7, p. 273)

Thermonuclear

Of or pertaining to nuclear reactions or processes caused by heat, especially to nuclear fusion caused by the intense heat of an atomic bomb explosion.

Thermoplastic

A plastic which softens upon the application of heat and rehardens upon

cooling. It can be softened and hardened repeatedly.

Thermoset Plastic

A plastic which undergoes a chemical change upon the application of heat and which does not appreciably soften or deform if later reheated.

Thermosphere

The region of the atmosphere in which the temperature increases continuously with altitude. (See Ionosphere)

Three-Way Valve

(See Valve, Three-Way)

Three-Wire System

A direct-current or single-phase alternating-current system comprising three conductors, one of which (the neutral wire) is maintained at a potential midway between the potential of the other two.

Thrust

In jet propulsion, the resultant force in the direction of motion, owing to the components of the pressure forces in excess of ambient atmospheric pressure, acting on all inner surfaces of the vehicle parallel to the direction of motion. Thrust less drag equals accelerating force.

Thrust Augmentation

(See Afterburning)

Thrust Chamber

In a liquid rocket, the assembly consisting of the injector, nozzle and combustion chamber in which mixing of liquid propellants takes place to form hot gases which are then ejected through a nozzle at high velocity to give momentum to the system. (See Fig. 10.53, p. 448)

Thrust Equalizer (Solid Propellant Rocket)

A device used to prevent motion of a solid propellant rocket in the event of inadvertent ignition by permitting discharge of exhaust gases from both ends to result in a zero net thrust. The device is closed off or otherwise inactivated when the rocket is readied for use. A typical design would provide a blowout disc in the head end approximately equal to the nozzle exit area.

Thrust Misalignment

The difference between the actual and desired direction of thrust in a propulsion system; it adversely affects dispersion, the greatest effect occurring early in the flight when the flight velocity is low.

Thrust Output

The net thrust delivered by a jet engine, rocket engine, or rocket motor.

Thrust, Pressure

The product of the cross-sectional area of the exhaust jet leaving the vehicle and the difference between the exhaust pressure and the fluid pressure.

Thrust, Specific

(See Specific Thrust)

Thrust Specific Fuel Consumption

A figure of merit for thermal jet engines; the ratio of pounds of fuel consumed per second to pounds of thrust. (See Eq. 7.3.5, p. 285)

Thrust Spoiler

As applied to a jet engine, a system of shutters over the end of the jet pipe to destroy most of the positive thrust at idling speeds, and thus reduce the landing run. Not in general use.

Thrust Termination Equipment

A component of the propulsion system uniquely used to terminate thrust (and thus acceleration) at a predetermined cutoff time to achieve proper positioning of the point of impact of the missile or payload.

Thrust, Static

The thrust produced by a jet engine, rocket motor, or the like, or by a propeller-engine combination, when held stationary.

Thrust Vector Control

A means of controlling a missile by use of jet deflection devices which, in response to appropriate signals from the autopilot, maintains proper attitude and path control.

Thunderstorms

Cumulonimbus clouds accompanied by lightning and thunder. Normally thunderstorms are accompanied by torrential rain for brief moments during the passage of the storm, but occassionally no precipitation reaches the ground. Often they cause hail and gusty surface winds of considerable velocity. Sometimes they are attended by tornadoes

which cause great damage. Vertical velocities inside thunderstorms are extremely erratic and as high as 120 mph.

Thyratron

A gas-filled grid-controlled soft tube which operates characteristically such that starting from a high negative grid potential, current flow occurs suddenly at some more positive grid potential, after which the anode current is independent of the grid, and must be stopped by reducing the anode potential. (Used in radars mainly for switching or triggering in modulator circuits. Lower power versions are used in control circuits.)

Tilt Angle

A mathematical artifice used to program the trajectory of ballistic missiles from the vertical ascent toward the horizontal to get "on target". In practice, the tilt is not a discrete angle but is slowly changed.

Time

(1) The mode of grouping sense impressions by the order in which events are observed. Abstract time, as used in mechanics and physics generally, is a parameter serving as the fundamental independent variable in terms of which the relative dynamic behavior of all physical systems may be compared. As a parameter it may take on all the succession of values of the real number continuum.

(2) Time (as commonly used) is an artificially developed reference, based on the daily rotation of the earth with respect to the sun. The speed of the earth in its orbit about the sun varies, and the length of the day, based on the rotation of the earth relative to the sun varies. The mean sun moves eastward in the celestial equator at a uniform rate equal to the average rate of the true sun in the ecliptic, thus removing the irregularities of apparent time. Time as measured by this means is called Civil Time. The difference between civil time and apparent time reaches a maximum value of nearly 16 1/2 minutes in November. To avoid confusion, the earth is divided into time zones, each 15 degrees wide in longitude, starting at the zero zone, extending 7 1/2 degrees each side of the zero meridian at Greenwich.

(3) Time measured by the earth's rotation in a star reference system is called Sidereal Time.

Time Constant

The time required for a varying quantity to reach (1-1/e) of its total change (approximately 63.2 percent of its total change): e.g., in electronics, in a capacitor-resistor circuit, the time in seconds for the capacitor to reach approximately 63.2 percent of its full charge after a steady voltage is applied; in an inductor-resistor circuit, the time in seconds required for the current to reach approximately 63.2 percent of its final value, after a steady voltage is applied.

In structural dynamics, the response of a structure to a transient load.

(See Eq. 6.13, p. 229)

Time-delay Relay

A relay in which the energizing or deenergizing of the coil precedes movement of the armature by an appreciable and generally determinable interval.

Time Sharing

(See Multiplexing)

Time, Sidereal

(See Sidereal Time)

Tip-Off

The angular momentum acquired by a missile due to the action of gravity as its forward supports leave the launcher before the aft supports.

Tip Rake

A geometrical characteristic of aerodynamic surfaces; the trailing edge tip is cut such that its angle with the missile centerline is less than the Mach angle.

Topping

Replacing propellants lost through vaporization and initial consumption from ground supply.

Tornados

Some thunderstorms, particularly the line-squall type, occasionally develop a violent whirl of air (or tornado) which extends down from the base of the cloud and touches the earth. It often draws up into the cloud again and may strike some

distance away or never reappear. Very low pressure prevails inside a tornado because of its great vorticity. Velocities of 200 to 300 mph are suspected in tornados.

Total Impulse

(See Impulse, Total)

Track Command Guidance

(See Guidance, Track Command)

Track-While-Scan

An electronic device used to detect a radar target, to compute its velocity, and to predict its future position without interfering with continuous radar scanning.

Traffic-Handling Capacity

The ability of a guidance or weapon system simultaneously to control multiple missiles against one or more targets.

For example, the active air-to-air homing guidance system is limited only by the number of missiles carried by the interceptor aircraft and the time available for launching the missiles. It is theoretically possible for the interceptor aircraft to launch more than one missile against the same target. In addition, it is possible for the interceptor aircraft to launch one missile against a target, break away, and launch another missile against a different target.

Trajectory

The path of a missile from launch to impact or destruct.

Design trajectories have restraints imposed by mission, velocity, altitude, q, temperature, etc.

Trajectory, Vacuum

The elliptical curve of any ballistic trajectory neglecting air friction.

Trajectory, Zero Lift

(See Zero Lift Trajectory)

Transconductance

Mutual conductance. A conductance (I/R or I/E) relating input and output. Also the small change in plate current in an electronic tube which results from a small change in grid voltage. Transconductance is equal to the amplification factor of a tube divided by the plate resistance.

Transcriber

A device for converting coded information back to its original state.

Transducer

(1) A device actuated by power from one system and supplying power in the same or any other form to a second system. These systems may be electrical, mechanical, or acoustical.

(2) A pickup or end organ in a telemetering system.

(See Beacon)

Transducer Gain

The ratio of the power that a transducer delivers to its specified load under specific operating conditions to the available power of the specified source. If the input and/or output power consists of more than one component, such as multifrequency signal or noise, then the particular components used and their weighting should be specified. This gain is usually expressed in decibels.

Transfer Function

A mathematical expression which expresses the relationship between the outgoing and incoming signals of a process, control element, system, device, etc. Shaping, restraints, band-pass and other characteristics are defined. A common expression for the transfer function is the Laplace transform of the network output to the Laplace transform of the network input, with all initial conditions set equal to zero.

The expression transfer characteristic can be used to refer either to the transfer function or the frequency-response when the initial conditions are all equal to zero.

Transfer Orbit

(See Orbit, Transfer)

Transfer Room

The transfer room below the erection area is connected to the control building by an underground cableway. It houses the relay racks, terminal boards, and other equipment necessary to route cables from the test stand to the control building.

Transfer Valve

An electrohydraulic or electromechanical device used to control the power circuit of a servo by means of an electrical signal. (See Valve, Three-Way; Valve, Four-Way)

Transient State

A condition in a dynamic system which implies a temporarily abnormal or erratic behavior of a variable such as speed, temperature, pressure, etc. Contrast steady state in which the variable is either held at a constant value or else changes uniformly with time.

Transistor

A nonlinear semi-conductor with three or more electrodes; a device which controls the flow of electrons by means of selective crystal properties of certain materials, e.g., germanium. Within limits a transistor can replace a vacuum tube. (See Fig. 6.29, p. 267)

Transistor, Junction

A solid state device in which the emitter and collector connections are large surface contact (low resistance). The emitter current is slightly larger than the collector current and the base current is very small. (Contrast with Point Contact Transistor.)

Transistor, Point Contact

A solid state device in which the emitter and collector connections are point contact (high resistance). The collector current is larger than the emitter current. (Contrast with Junction Transistor.)

Transition Engineering

The engineering associated with the movement of a project from research and development into detail design and production.

Translunar Space

(See Space, Translunar)

Transmissibility

The ratio of transmitted force to the applied force in a mechanical system. (See Eq. 4.20, p. 180)

Transmission Loss (or Gain)

The transmission loss of a system joining a load having a given electrical, mechanical rectilineal, mechanical rotational or acoustical impedance, and a source having a given electrical, mechanical rectilineal, mechanical rotational or acoustical impedance and which impresses a given electromotive force, force, torque or pressure is expressed by the logarithm of the ratio of the power actually delivered to the load to the power delivered to the load under some reference condition. For a loss the reference power is greater. For a gain the reference power is smaller.

Transmitter, Amplitude-Modulated

A transmitter which transmits an amplitude-modulated wave. In most amplitude-modulated transmitters, the carrier frequency is stabilized.

Transmitter, Crystal-Controlled

A transmitter whose carrier frequency is directly controlled by the electromechanical characteristics of a piece of material of crystalline structure (a crystal).

Transmitter, Crystal-Stabilized

A transmitter employing automatic frequency control, in which the reference frequency is that of a crystal oscillator.

Transmitter, Double-Sideband

A transmitter which transmits the carrier frequency and both sidebands resulting from the modulation of the carrier by the modulating signal.

Transmitter, Frequency-Modulated

A radio transmitter which transmits a frequency-modulated wave.

Transmutation

The process whereby an atomic nucleus of one species changes into one of a different species, often accomplished by bombardment with nuclear particles, as in a cyclotron or nuclear reactor.

Transonic

(See Sonic, Tran)

Transpiration Cooling

(See Sweat (Transpiration) Cooling)

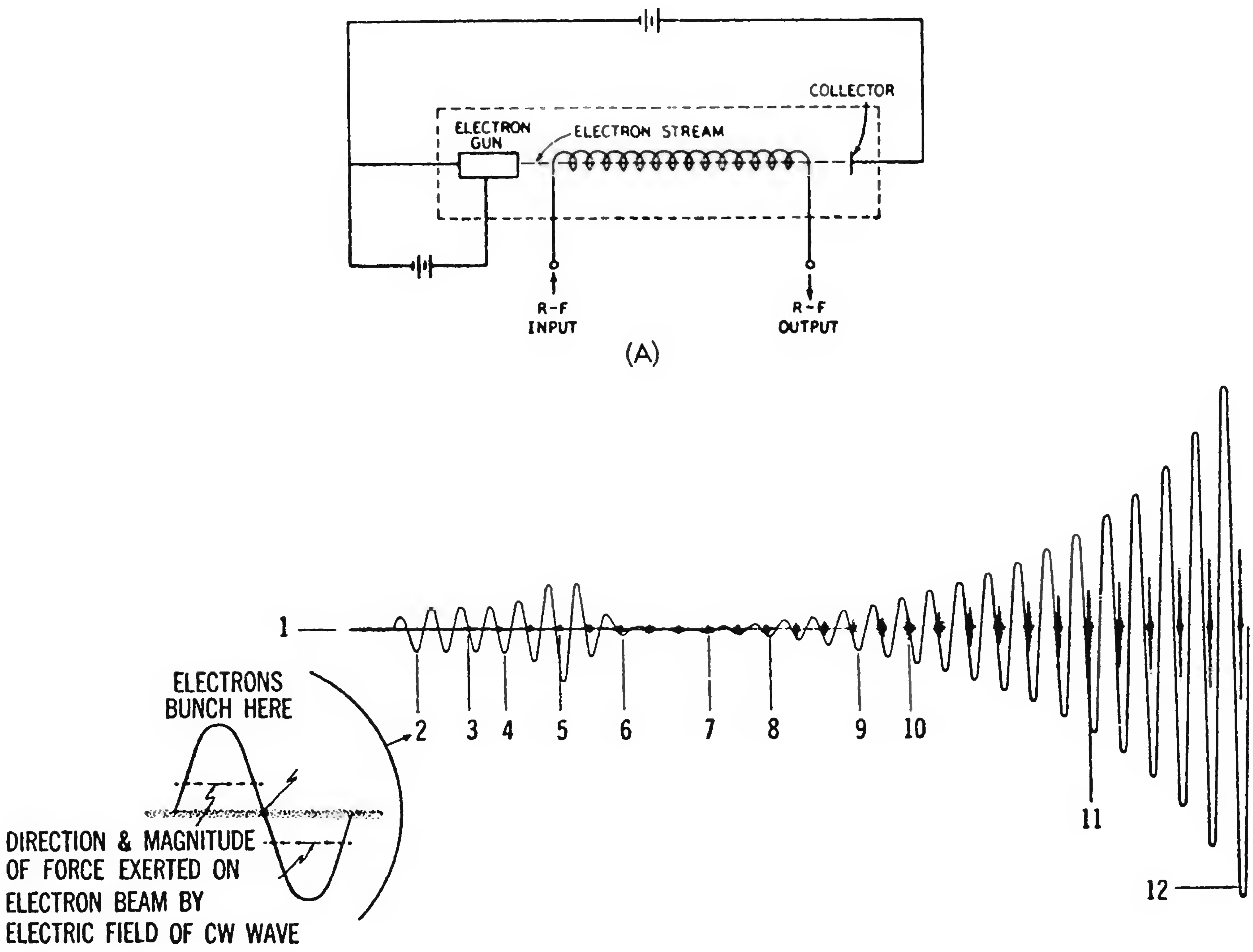
Trans-planetary Space

(See Space, Trans-planetary)

Transponder

Usually a beacon containing a receiver and transmitter. The purpose is to increase the energy level of the target or missile signal in order that the surveillance range can be extended. The transponded signal may be at the same frequency as the surveillance radar or it may be preset at some value which is perhaps 50 megacycles different. Under these conditions the surveillance radar transmits at one frequency and transponder transmits back at another frequency.

FIG. 10.63 SCHEMATICS OF TRAVELING WAVE TUBE



(B)
Operational Schematic

From Reintjes and Coate, "Principles of Radar," Copyright 1952. McGraw-Hill Book Co., Inc.

Trapped Propellant

In a liquid rocket engine, the residual propellant in the feed lines which cannot be used because of inadequate suction head. Trapped propellant plus engine dry weight equals engine net weight.

Traveling-Wave Tube

A broadband microwave tube which depends for its characteristics upon the interaction between the field of a wave propagated along a waveguide and a beam of electrons traveling with the wave. In this tube, the electrons in the beam travel with velocities slightly greater than that of the wave, and on the average are slowed down and bunched by the field of the wave. (Used as a microwave amplifier.) (See Fig. 10.63)

Tridop

An elliptical instrumentation or measuring system using the Doppler frequency shift resulting from missile velocity as intelligence.

Trigger Circuit

A multivibrator circuit in which either of the two tubes can operate stably, but the firing of either tube extinguishes the other. The "flip-flop" action is produced by a trigger pulse in the grid of both tubes Modifications make possible the use of positive or negative triggering, a double flip-flop or one shot operation. (Used in radar and counting circuits.)

Trim

In aerodynamics, a steady-state (static) condition wherein the wing of a missile is deflected to provide the necessary lifting or normal force; it is required

that the overall moments acting on the full configuration missile must be zero.

The missile is said to be trimmed when it is at its equilibrium (total moments equal zero) angle of attack for a given control surface setting.

Triple Point

In supersonic aerodynamics, the point of intersection of the incident front, the reflected front, and the Mach front.

Tropopause

The boundary or zone of transition between the troposphere and the stratosphere. It varies in height from about 55,000 feet at the equator to 25,000 feet over the poles. The height also changes with the seasons and with the passage of cyclones and anticyclones. The temperature at the tropopause ranges from approximately -67° F above the poles to about -100° F over the equator. (See Fig. 10.5, p. 400)

Troposphere

The region of the atmosphere extending from the surface of the earth up to the tropopause (approximately 10 miles); characterized by convective air movements and a pronounced vertical temperature gradient decreasing with altitude, in contrast to the convectionless and almost vertically isothermal stratosphere above the tropopause. It contains about 75% of the total weight of the atmosphere.

Tropospheric Wave

A radio wave that is propagated by reflection from a place of abrupt change in the dielectric constant or its gradient in the troposphere. In some cases the ground wave may be so altered that new components appear to arise from reflections in regions of rapidly changing dielectric constants; when these components are distinguishable from the other components, they are called tropospheric waves.

Tube, Local Oscillator

An electron tube in a heterodyne conversion transducer to provide the local heterodyning frequency for a mixer tube.

Tube, Soft

(1) A tube which has not been completely evacuated, or a vacuum tube which has lost part of its vacuum due to gas released from the electrodes and envelope.

(2) A tube which has been evacuated and recharged with an inert gas.

Tubular Grain

A solid propellant grain cast in the form of a tube which burns with a constant value of K_n. The thickness of the propellant grain, termed the web thickness, determines duration of the burning. (See Fig. 10.16, p. 423)

Turbojet

A thermal jet engine whose air is supplied by a turbine-driven compressor; the turbine being activated by exhaust gases from the combustion chamber. (See p. 285)

Turboprop (Propeller-turbine Engine; Prop-jet)

A gas-turbine engine designed to drive a propeller for use at intermediate aircraft speeds.

Turbulent Flow

In aerodynamics, a condition wherein the air close to the surface is of a turbulent nature; that is, contains unpredictable eddies and generally rough flow. The opposite of laminar flow.

Two-Dimensional Flow

In aerodynamics, a flow in which two Cartesian coordinates are sufficient to specify conditions. The fluid undergoes a significant change of direction in one plane only, i.e., at right angles to the direction of the flow, as in the case of flow over a wing of infinite span. Wind tunnel tests are facilitated by two-dimensional observations, assuming uniform conditions along any line perpendicular to the walls of the tunnel.

Two-stage Compressor

Normally a compressor of the centrifugal type in which the compressed air from the low-pressure or first stage, is passed into the second stage and recompressed. This affords higher compression ratios than the theroetical maximum of approximately 4:1 available from a single-stage centrifugal compressor.

Twisted Pair

A cable composed of two insulated conductors twisted together either with or without a common covering.

Two-Stage Missile
(1) Any missile consisting of two stages or phases of powered flight using two distinct power plants.
(2) A missile consisting of a booster stage and a second or sustainer stage. At staging the booster or first stage (consisting of propulsion system, tankage, structure and autopilot) is discarded. The second stage engine may be required to start at altitude or it may be ground started giving thrust during the boost phase.
(See Tandem Missile)

Type Test
A test made on a typical or sample article to demonstrate that the particular design is adequate for its intended use. A type test is usually "one of a kind" and the test input may be to design extremes: e.g., structural test to failure.

U

UAL
Unit Authorization List. An allowance list of equipment for each operational unit.

UAM (Underwater-to-Air Missile)
(See Missile, Ground-to-Air; Model Designation)

UEE
(See Unit Essential Equipment)

UME
(See Unit Mission Equipment)

UOC
(See Ultimate Operational Capability)

UR
Unsatisfactory Report. Used by Air Force activities to report a field failure or malfunction.

USM (Underwater-to-Surface Missile)
(See Missile, Ground-to-Ground; Model Designation)

Ullage
The volume of a propellant tank in excess of the propellant. It is provided to allow for thermal expansion of the propellant and for accumulation of gaseous products evolved from the propellant.

Ultimate Load
(See Load, Ultimate)

Ultimate Operational Capability (UOC)
That phase of a weapon system's use which follows IOC (Initial Operating Capability) and which utilizes unit equipment.

Umbilical Cord
A cable fitted with a quick disconnect plug on the missile, through which missile equipment is controlled and tested while the missile is still attached to launching equipment or parent plane.

Uncage
Electrical disconnection of the erection circuitry in a displacement gyroscope system.

Underground Burst
A nuclear explosion with its center of detonation beneath the surface of the ground.

Underground Launcher
A launching complex capable of launching a missile from underground. Contrast with underground storage.

Underwater Burst
A nuclear explosion with its center of detonation beneath the surface of the water.

Underwater-to-Air Missile (UAM)
(See Missile, Ground-to-Air; Model Designation)

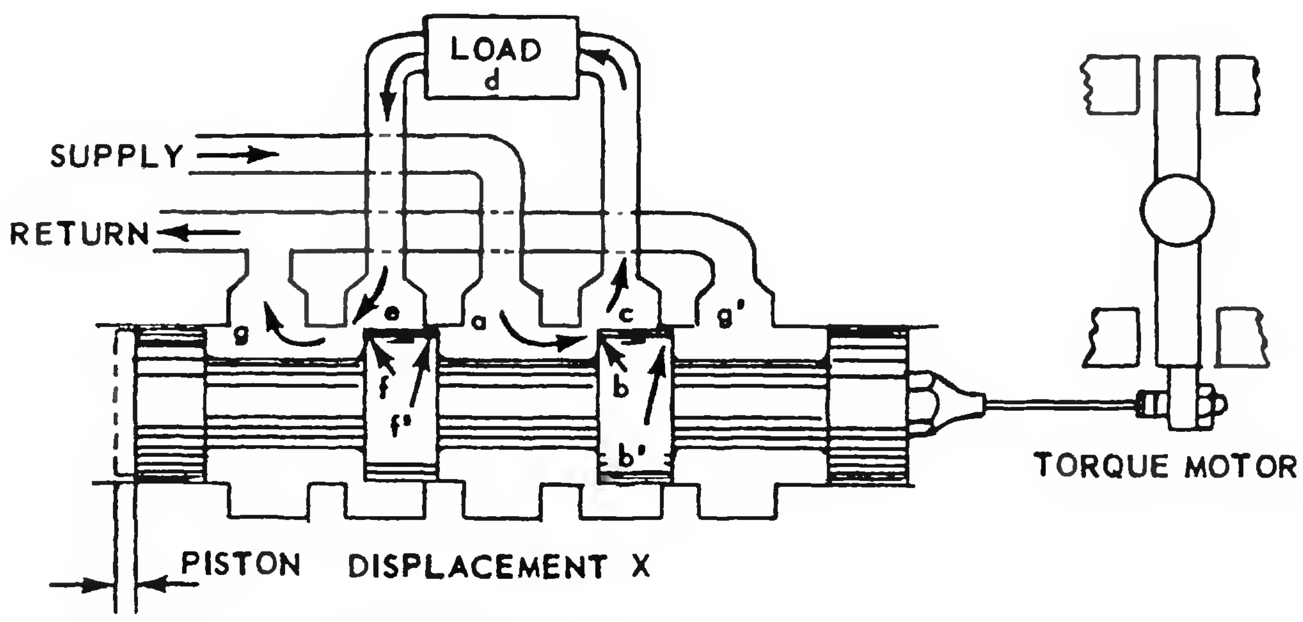
Underwater-to-Surface Missile (USM)
(See Missile; Surface-to-Surface; Model Designation)

Unit Equipment
A group of components which, when operating together, accomplish a specified task: e.g., airborne unit (missile), radar, Doppler, launching and ground-handling equipment.

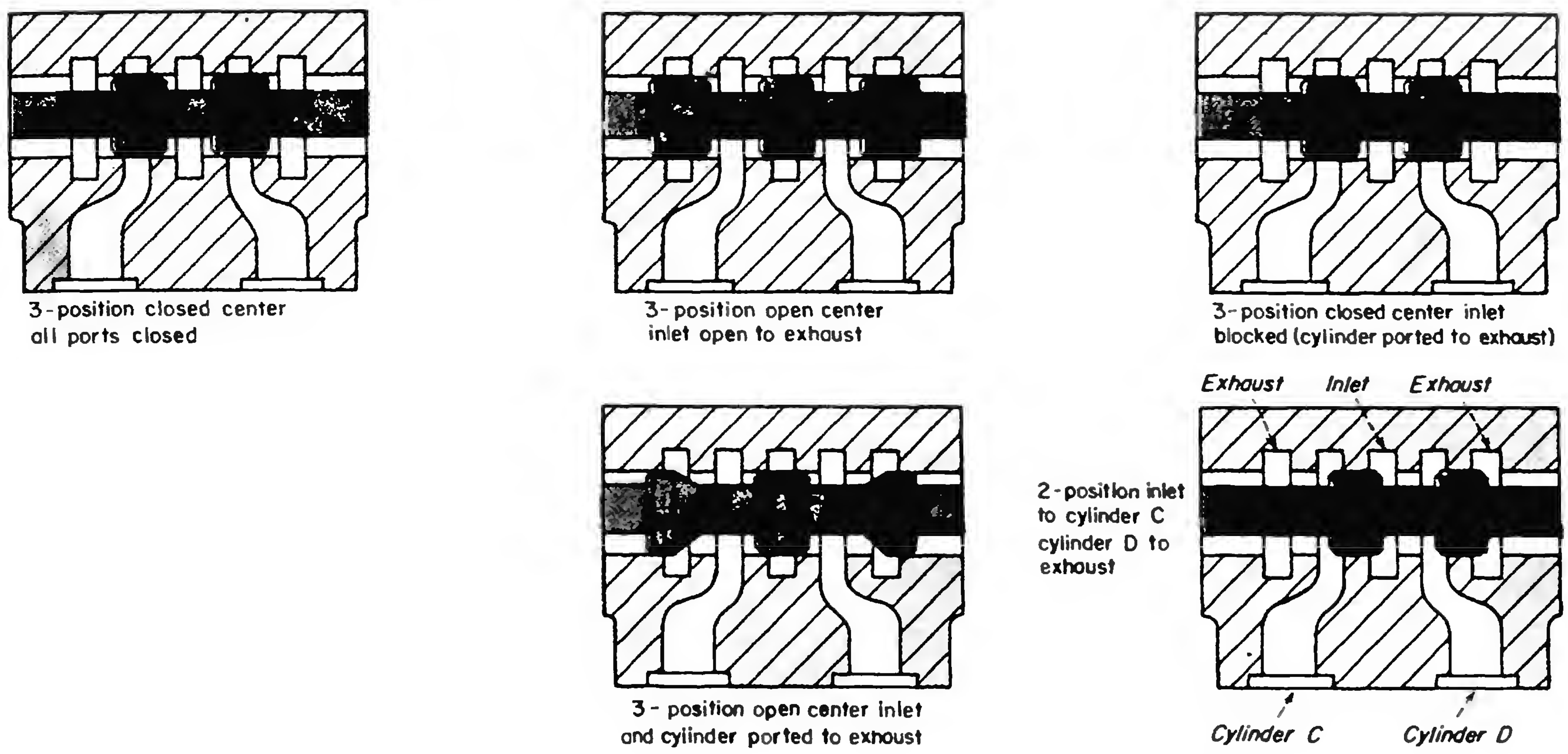
Unit Essential Equipment (UEE)
That portion of the unit mission equipment for T/O units which is air transportable and required to perform the mission.

Unit Mission Equipment (UME)
Those items of equipment authorized in the Master Equipment Allowance List (MEAL) or special lists of equipment for specific T/O units as authorized by Headquarters USAF. This equipment will normally be moved with the unit from location to location.

FIG. 10.64 FOUR-WAY VALVE SCHEMATICS



(a) Conventional Four-Way Control Valve



(b) Valve Configurations

Unitization (Unitized Design)

In electronic design, the grouping together of functional components into an assembly, often subminiaturized.

Unrestricted Propellant

(See Propellant, Unrestricted)

Unstable Servo

(See Servo, Unstable)

Up-Time

The calendar time in which the system is considered in condition to perform its required function.

Up-Wash

The slight upward flow of air just prior to its reaching the immediate vicinity of the leading edge of a rapidly moving airfoil or wing; a damming up of the air under the airfoil and this condensed mass of air forces the newly arrived mass to flow upward.

User Test

A missile or weapon system test conducted by the ultimate using activity instead of the development or evaluation agency.

V

Vacuum Trajectory

(See Trajectory, Vacuum)

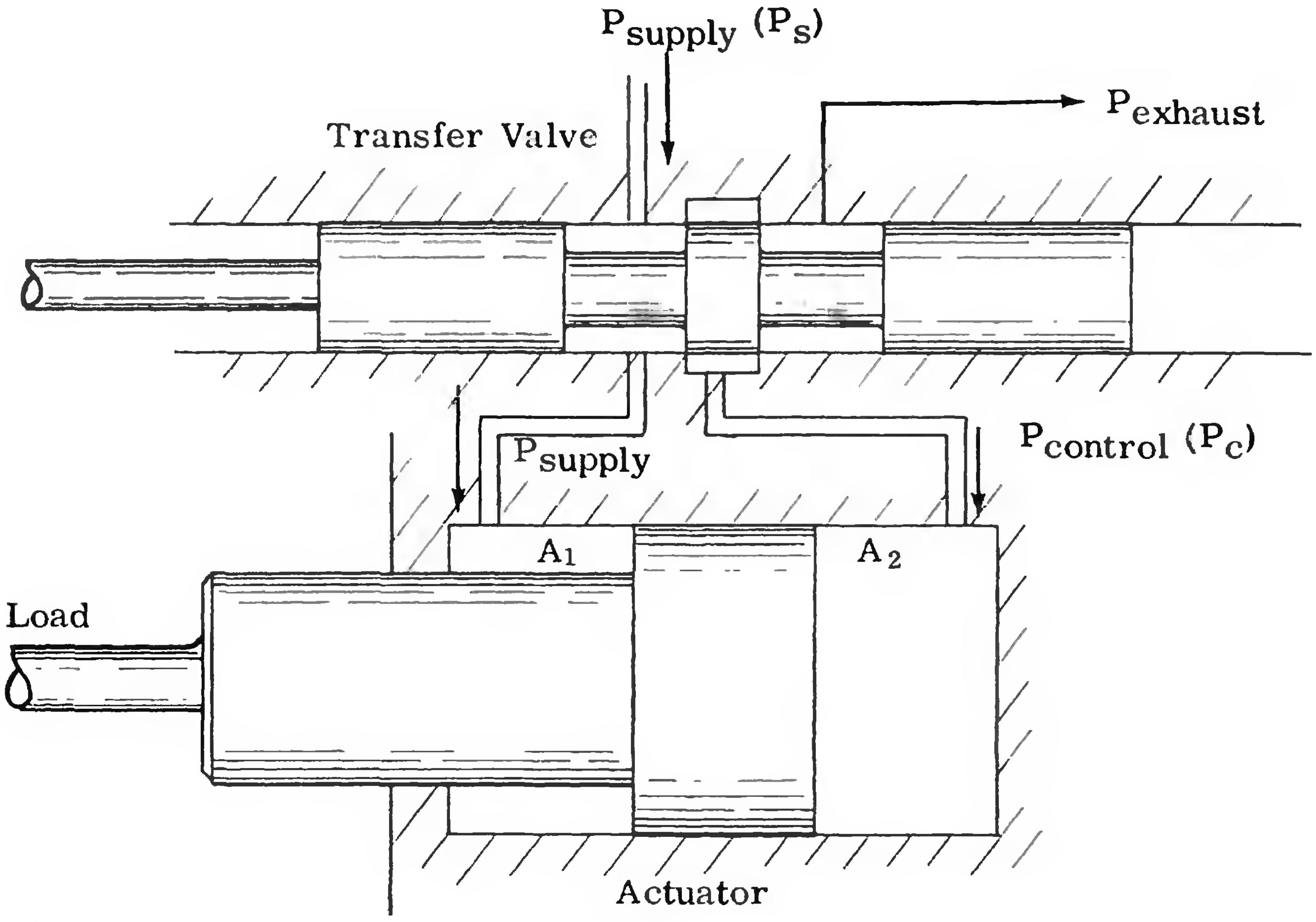
Valley Breeze

On hot days, uneven terrain gives rise to uphill breezes, i.e., from the valley up mountain or hill slopes. This breeze is known as a valley breeze; it is an anabatic wind. With sunset, the breeze dies.

Valve, Four-Way (pressure-drain-load-load)

A hydraulic valve which uses four orifices to control the load flow or pressure for bi-directional motion. One

FIG. 10.65 THREE WAY VALVE SCHEMATIC



pair of orifices is used for each direction. Basically, the four-way valve operates as two three-way valves in pushpull. As the movable member moves in one direction the load pressure between one pair of orifices increases while the pressure between the other decreases. Because of this push-pull action the four-way valve produces a greater force output, is more linear over a larger range, and is less susceptible to supply pressure variations; it has the disadvantage of increased cost. In servo applications the four-way valve is most commonly used. Four-way valves may be closed center or open center types. (See Fig. 10.64, p. 551)

Valve, Relief

An hydraulic or pneumatic system element designed to limit the pressure to a maximum safe value.

Valve, Three Way

A type of transfer valve-actuator combination in which only one valve port is used and the actuator output is achieved by metering the working fluid into or out of only one actuator chamber. The system pressure always acts on the small area of the actuator. Thus if A_2 is twice the area of A_1, the available control pressure is one half the supply pressure under no load conditions. The load induced pressure is:

$$P_L = P_c - \frac{P_s}{2} \text{ if } P_c = o$$

(See Fig. 10.65)

Valve, Transfer

(See Transfer Valve)

Valve, Vent

(See Vent Valve)

Variplotter

Trade name for a device which automatically plots or reads a graph by means of a photocell system.

Varistor

A two-electrode semiconductor device having a voltage-dependent, nonlinear resistance. The resistance is markedly reduced when the applied voltage is increased. (Used for voltage protection.)

Vector

The positioning of an interceptor with respect to its target through commands issued from a separate control station.

Vectoring Error

The radial distance between desired and actual tracks of an interceptor vectored to a target by a separate control station.

Vectoring Requirement

The boundary loci of tracks within which a given interceptor must pass in order to acquire a given target with its

weapons control system and thereafter launch its missiles to obtain the desired probability of kill.

Veering Wind

Any clockwise change in wind direction is known as veering of the wind. It is opposite of a backing wind.

Velocity, Absolute

The highest velocity theoretically attainable, i.e., the velocity of light (3 x 10^{10}cm/sec).

Velocity (at burnout)

The velocity of a missile when propulsion ceases; especially important in ballistic and boost-glide missiles.

Velocity, Escape

That velocity required by a missile in order to escape from the earth's gravitational field. (See Fig. 8.2, p. 313 and 8.3, p. 314)

Velocity Limiting Servo

(See Servo, Velocity Limiting)

Velocity, Orbital

The velocity of a satellite missile which circulates indefinitely around the earth and outside its atmosphere.

Velocity Shock

The shock condition occurring in equipment when a sudden change occurs in the linear velocity, or in the direction of motion, of the equipment or its mount. (See Shock; Shock Motion)

Vent-Valve

A valve used in a hydraulic/pneumatic system to provide a means for bleeding or venting the container.

Vernier Engines

Rocket engines (usually liquid) used to adjust the final velocity of a long range ballistic missile. The engines are also used to correct heading errors.

Vibration, Forced

Vibration of a body resulting from application of external force during an explicit time interval.

Vibration, Free

Vibration of a body occurring without external forces being applied during the time the phenomenon is occurring.

Vibration, Natural Mode of

The set of amplitude ratios and phase differences in a system undergoing free vibrations at a single natural frequency.

Vibration, Steady-State

Vibration in which the motion of every body in the system is periodic.

Video Amplifier

An electronic device which provides wide band operation in the frequency range from approximately 15 cycles per second to 5 megacycles per second. Used to give a signal of sufficient intensity to modulate a cathode-ray tube (either by intensity modulation or deflection modulation, according to the type of display used), or to operate some auto-following or other special circuit.

Video Frequencies

Frequencies existing in the demodulated output of a television camera as a result of scanning the image being transmitted. The range is from almost zero to well over 4 megacycles. Also termed visual frequencies.

Visual Inspection

(See Inspection, Visual)

Voltage Divider

A network used for the purpose of tapping off a fractional part of the electrical potential difference existing between the input terminals.

Vulnerability

The susceptibility of a target to a damage agent.

W

WR

War Reserve.

WS

Weapon System.

WSM

Weapons System Manager.

WSPO

(See Weapon System Project Office)

WSSM

Weapon System Supply Manager.

Waiver

A contractual agreement to permit acceptance by the Procuring Agency of a piece of hardware even though the part or equipment does not conform to the applicable specification and/or drawing. Contrast with Deviation. (See Deviation)

Wake

The turbulent volume of gas enclosed by the boundary layer and originating

from the base of a missile.

Wamoscope (WAve MOdulated oscilloSCOPE)

A cathode ray tube system including detection and display of a microwave signal in a single envelope amplification, thus eliminating the local oscillator, mixer, IF amplifier, detector, video amplifier and associated circuitry in a conventional radar receiver. Tubes are available for the range of 2000 to 4000 mc.

Warhead

The destructive agent of a missile which is activated by proper fuze and S and A action.

Warhead, Blast

A warhead designed primarily to convert its latent energy to a source of high pressure which is propagated away from the original warhead position. Damages targets by subjecting the target surface or structure to extreme overpressure.

Warhead, Blast Cluster

A number of sub-warheads, or submissiles, carried by a parent warhead or missile each of which is in itself a missile equipped with a full complement of armament.

Warhead Booster

The end element of an explosive train whose detonation initiates the warhead detonation.

Warhead, Fragmenting

A warhead specifically designed to emit a maximum number of specially shaped fragments having optimum propagation properties. The blast effect which accompanies the emission of the fragments is a secondary effect and is not generally considered in the assessment of the effectiveness of the fragmenting warhead.

Warhead Gain

The increase in damage effectiveness of a non-isotropic warhead achieved by enhancing the effects in particular directions at the expense of other directions.

Warhead, Isotropic

A warhead whose damage effect is the same in all directions:

Max. range of isotropic fragmentation warhead $-\sqrt[2]{\text{warhead weight}}$

Max. range of isotropic blast warhead $-\sqrt[3]{\text{warhead weight}}$

Warhead Pattern

A description of the relative angular variation of the damage parameter of a non-isotropic warhead. The warhead pattern is the spatial distribution of some significant warhead damage or emission parameter in a particular set of coordinates and in a particular environment.

Warhead Yield

The energy release of a nuclear weapon, usually expressed in kilotons (1,000 tons) of TNT equivalent.

Washboard Course

A generic term applied to roads and test areas used to evaluate equipment when subjected to a rough and irregular but known road characteristic. (See Belgium Block Road)

Water Deluge System

A high-capacity, high-pressure water system at the test and launch stands for washdown, fire prevention, and fire fighting.

Watt

The practical unit of electric power and, in a direct-current circuit, equal to volts multiplied by amperes. In an alternating-current circuit, true watts are equal to effective volts multiplied by effective amperes, them multiplied by the circuit power factor.

Wave, Compressive

(See Shock Wave)

Wave, Drag

(See Drag)

Wave, Ground

The waves formed in the ground by an explosion. They are of three types: longitudinal waves (compression), transverse waves (shear), and surface waves (similar to water ripples). They can be induced by direct ground shock (as in a ground or sub-surface burst) or by blast transmitted through the air (as in any type of burst).

Wave Guide

A device, consisting either of a metal tube or dielectric cylinder, capable of propagating electromagnetic waves through its interior. The widths or diameters of such guides are determined

by the frequency to be propagated. Metal guides may be evacuated, air filled, or gas filled, and are generally rectangular or circular in cross section. Dielectric guides consist of solid dielectric cylinders surrounded by air. (See p. 270)

Wave, Square

(See Square Wave)

Weapon Effectiveness

The degree to which a weapon system can perform its mission with minimum drain on national resources.

Weapon Evaluation (Analysis)

The science of determining weapon effectiveness through technique of operations research.

Weapon System

A group of tactical devices which together perform a mission, i.e., detect a target, identify it as friend or foe, deliver a payload upon it, and assess the resulting damage. The complete Weapon System includes the equipment, skills, techniques and personnel required for providing the desired role or mission in the operational environment.

Weapon System Project Office (WSPO)

A central point for management control of one or more weapon system programs. It is established to achieve proper phasing of actions in development, procurement, maintenance, and supply, thereby insuring timely delivery and support of weapon systems. An important function of this office is that of providing a central contact point for industry and Air Force relations.

Weapon System Specification

A top specification developed in accordance with military requirements which outlines the design criteria and performance requirements for the weapon, the support equipment, facilities and manpower.

Wearout Failure

(See Failure Modes)

Weathercock Stability

An aerodynamic characteristic of a body which points it into the relative wind.

The partial derivatives of yawing and pitching moments with respect to angles of attack in yaw and pitch establish the stability characteristics. (See Stability Derivatives)

Web

In unrestricted-burning solid propellant rocket grains, the minimum distance which can burn through, as measured perpendicular to the burning surface. (See Fig. 10.16, p. 423)

Weight Bogey

A system or group weight established as a target at the start of a design. (It is usually fixed by the weight group and is periodically adjusted as a program progresses.) Also termed Target Weight.

Weight, G

(See Accelerometer; G-Weight)

Weights Report

A report commonly used in missile design which includes detail weights (estimated, calculated or actual weights), mass distribution, moments, location of center of gravity of each component, weight distribution by station for inertial calculations, weight and center of gravity variation as function of time and/or velocity or Mach number for boost and flight phases. Usually three weight reports are submitted: Estimated, Calculated, and Actual.

White Noise

(1) Random noise, such as shot noise and thermal noise which has a constant energy per unit bandwidth that is independent of the central frequency of the band. The name is drawn from the analogous definition of white light.

(2) The electrical disturbance caused by the random movement of free eletrons in a conductor or semi-conductor. Since the electrical energy in this type of noise is evenly distributed throughout the entire frequency spectrum, it lends itself to use in testing frequency response of amplifiers, speakers, etc.

Wilson Cloud

A misty cloud of short duration, caused by the condensation of water vapor in the air due to the drop in temperature that accompanies the passage of the refraction in a shock wave.

Wind, Cross

(See Cross Wind)

Wind, Cyclostrophic
(See Cyclostrophic Wind)

Wind, Geostrophic
(See Geostrophic Wind)

Wind, Katabatic
(See Katabatic Wind)

Window
Strips of frequency-cut metal foil, wire or bars which may be dropped from aircraft or missiles or expelled from shells or rockets as a radar countermeasure. (See Reflector, Confusion)

Wind Profile
A graphical distribution of the steady wind speed over a large altitude range.

Wind, Relative
The velocity and direction of the air with reference to a body moving in it. It is usually determined from measurements made at such a distance from the body that the disturbing effect of the body upon the air is negligible.

Winds
In meteorology winds can be divided into categories:

(1) Gradient winds blow in accordance with the existing pressure gradient, centrifugal force and Coriolis force. There are two sub-types:
  (a) Cyclonic winds blow counterclockwise about regions of relatively low pressure in the northern hemisphere and clockwise in the southern hemisphere.
  (b) Anticyclonic winds blow clockwise about regions of relatively high pressure in the northern hemisphere and counterclockwise in the southern hemisphere.

(2) Geostrophic winds blow in accordance with the pressure gradient but only where the pressure gradient is balanced by the Coriolis force. They are, therefore, winds which blow in straight or nearly straight lines over the earth. Geostrophic winds are not possible at the equator because there is no Coriolis force present.

(3) Cyclostrophic winds blow cyclonically in both hemispheres in wind systems where the pressure gradient is balanced by centrifugal force in the absence of the Coriolis force. Cyclostrophic winds occur near the equator as hurricanes and other local less intense vortices.

(4) Antitriptic winds are small-scale, short duration winds which blow, in general, along the pressure gradient. Land and sea breezes are of this type.

In general, winds are mainly gradient winds. Many strictly local winds blow over relatively small regions. Most of these occur where there is sharp contrast in surface temperature over a relatively small distance or where terrain is highly irregular. Sea breezes blow from cool water to heated land during the heat of day. Land breezes blow from cooled land to warmer water during the cool of the night. Valley breezes blow upslope in valley-hill terrain during sunny days, and mountain breezes blow downhill in a reverse manner during darkness. Mountain breezes often become very strong and extremely variable as a result of large-scale eddies and venturi effects in mountain passes. (See Beaufort Wind Scale)

Wind Scale
(See Beaufort Wind Scale)

Wind Shear
The average wind gradient; the difference in the wind velocity at two altitudes divided by the altitude increment. The units are ft per sec/1000 ft.

Wind Tunnel
A test device for producing a controlled wind or air stream in which objects can be placed for investigating the air flow about them and the aerodynamic forces exerted on them.

Wind, Veering
(See Veering Wind)

Wing Control
A method of aerodynamically controlling a missile wherein the control surfaces are located near the center of the body and also become the main lifting surface; tail surfaces are mounted at the rear of the missile mainly for stabilizing purposes.

Wing-Control-During-Boost
A technique used for boost phase attitude stabilization wherein winged missiles are controlled as a Canard

configuration. After the booster rocket is jettisoned or staged the wings may be used for midcourse control.

Wing Loading

For a missile in level flight, the ratio of load on its wing to the wing area.

Winterization

Preparation of material to permit storage and operation in frigid regions by such means as insulation against cold, addition of heating elements, changes in lubricants, and changes in dimensional clearances of parts to a point where operation at extremely low temperature is reasonably efficient.

Wiring Diagram

A drawing that indicates the actual make-up of a unit or component. All parts, wiring, and connections are shown.

Wobbulation

(1) Similar to gyro nutations; a source of drift in single axis gyros.
(2) Variation of a steady-state frequency for test purposes.

Wobbulator

A device, usually mechanical, used to frequency-modulate an oscillator for test purposes. A small trimmer capacitor rotating at constant velocity across the frequency-determining network of the oscillator is an example.

Word

In digital computer applications, an instruction, a number or an arbitrarily coded quantity.

Working Load

(See Load, Working)

Wow

Speed variation in reproduced sound, i.e., a low-frequency flutter.

X

X

The letter "X", when used as a prefix in the designation of a guided missile, indicates that the missile is an experimental model: e.g., XSM-65.

X-BAND

A radio frequency band of 5,200 to 11,000 megacycles with wave lengths of 5.77 to 2.73 centimeters respectively. (See Fig. 6.5, p. 239)

x time, X time

X - time is used for timing events prior to missile liftoff.

X + time is used for timing events after ignition but prior to missile liftoff.

Y

Y

The letter "Y", when used as a prefix in the designation of a guided missile, indicates that the missile is a prototype model which is produced in limited numbers for operations tests: e.g., YTM-61.

Y_k

(See Propellant Loading Ratio)

Yield Point

The load per unit of original cross section at which, e.g., in soft steel, a marked increase in deformation occurs without increase in load. In other steels and in nonferrous metals, yield point is the stress corresponding to some definite and arbitrary total deformation, permanent deformation of slope of the stress deformation curve; this is more properly termed the yield strength. (See Yield Strength)

Yield Strength

Stress corresponding to some fixed permanent deformation such as 0.1% or 0.2% offset from the modulus slope.

Z

ZI

Zone of Interior

Zebra Time

Time measured from Greenwich Mean Time.

Zenith

The point in the celestial sphere directly overhead.

Zenith-Nadir Axis

A line connecting the zenith and nadir of an observer.

Zero-Length Launching

A technique in which first motion of the missile removes it from the launcher. A zero-length launcher orients the missile initially but has no significant effect on the missile flight path.

Zero-Lift Drag

The total drag upon a missile experiencing no lift. The integral of all axial

components of forces acting on the outside of a body with attached flow conditions at the lip of the inlet or of a cylindrical body (which is the usual design for the main body section of a guided missile). The forces are caused by viscous phenomena (skin friction) only.

Zero Lift Trajectory
A trajectory in which the control system acts to maintain a condition of no aerodynamic lift on the missile.

Zero Velocity Error Servo
(See Servo Order)

Zip Fuels
(See Fuels, Zip)

ABBREVIATIONS

A

AAM - Air-to-Air Missile
ABL - Allegheny Ballistics Laboratory; Cumberland, Maryland
ABMA - Army Ballistics Missile Agency
ADC - Air Defense Command
ADCC - Air Defense Control Center
ADDC - Air Defense Direction Center
ADIZ - Air Defense Identification Zone
ADW - Air Defense Warning
ADWKP - Air Defense Warning Key Point
AEC - Atomic Energy Commission
AEDC - Arnold Engineering Development Center; Tullahoma, Tennessee
AEDD - Air Engineering Development Center
AEW - Airborne Early Warning
AFAC - Air Force Armament Center; Eglin Air Force Base; Valparaiso, Florida
AFC - Automatic Frequency Control
AFCRC - Air Force Cambridge Research Center; Laurence G. Hanscom Field; Bedford, Massachusetts
AFFTC - Air Force Flight Test Center; Edwards Air Force Base; Edwards, California
AFMDC - Air Force Missile Development Center; Holloman Air Force Base; Las Cruces, New Mexico
AFMTC - Air Force Missile Test Center; Patrick Air Force Base; Cocoa, Florida
AFOSR - Air Force Office of Scientific Research; Washington, D. C.
AFPO - Air Force Procurement Officer
AFPR - Air Force Plant Representative
AFPTRC - Air Force Personnel and Training Research Center; Lackland Air Force Base; San Antonio, Texas
AFSWC - Air Force Special Weapons Center; Kirtland Air Force Base; Albuquerque, New Mexico
AFSWP - Air Force Special Weapons Project
AFOSR - Air Force Office of Scientific Research
A-G - Aerojet General Corporation, Azusa, California
AGARD - Advisory Group for Aeronautical Research and Development
AGC - Automatic Gain Control
AGM - Air-to-Ground Missile
AI - Air Intercept Radar
AIA - Aircraft Industries Association
AIGS - All-Inertial Guidance System
AM - Amplitude Modulation
AMA - Air Materiel Area
AMATC - Air Materiel Armament Test Center
AMC - Air Materiel Command; Wright-Patterson Air Force Base; Dayton, Ohio
AMTI - Airborne Moving Target Indicator
AN - Army-Navy
ANC - Army-Navy-Commercial
APGC - Air Proving Ground; Eglin Air Force Base; Valparaiso, Florida
APL/JHU - Applied Physics Laboratory/ The Johns Hopkins University; Silver Spring, Maryland
APS - Accessory Power Supply
APU - Auxiliary Power Unit
AQ - Aircraft Quality
AQL - Acceptable Quality Level
ARDC - Air Research and Development Command; Baltimore, Maryland
ARINC - Aeronautical Radio, Incorporated
ARL - Acceptable Reliability Level
ASCOP - Applied Science Corporation of Princeton; Princeton, New Jersey
ASESA - Armed Services Electro Standards Committee
ASETC - Armed Services Electron Tube Committee
ASG - Aeronautical Standards Group
ASI - Ammended Shipping Instructions
ASM - Air-to-Surface Missile
ASTIA - Armed Services Technical Information Agency; Dayton, Ohio
ATC - Air Training Command
ATI - Air Technical Intelligence
ATIC - Air Technical Intelligence Center

ATRC - Air Training Command; Scott Air Force Base; Belleville, Illinois
AUM - Air-to-Underwater Missile
AWS - Air Weather Service

B

BAR - Bureau of Aeronautics Representative
BDA - Bomb Damage Assessment
BDS - Bomb Damage Survey
BFO - Beat Frequency Oscillator
BI-APS - Battery Inverter Accessory Power Supply
BMD - Ballistic Missiles Division, Air Research and Development Command/Formerly designated WDD (Western Development Division)/; Los Angeles, California
BMO - Ballistic Missiles Office, Air Materiel Command
BOD - Beneficial Occupancy Date
BSE - Base Support Equipment
BTL - Bell Telephone Laboratories; Whippany, New Jersey
BuAer - Department of the Navy, Bureau of Aeronautics
BuOrd - Department of the Navy, Bureau of Ordnance
BuShips - Department of the Navy, Bureau of Ships
BuYdsDcks - Department of the Navy, Bureau of Yards and Docks

C

CAA - Civil Aeronautics Administration
CAL - Cornell Aeronautical Laboratory; Buffalo, New York
CCAAFB - Cape Canaveral Auxiliary Air Force Base; Cape Canaveral, Florida
CEA - Circular Error Average
CEP - Circular Error Probable
CFE - Contractor Furnished Equipment
CIA - Central Intelligence Agency
CNO - Chief of Naval Operations
COC - Air Division Combat Operations Center
ConAC - Continental Air Command
ConAD - Continental Air Defense
ConUS - Continental United States
Convair - A Division of General Dynamics Corporation; San Diego, California
CorEng - Corps of Engineers
CPFF - Cost-plus-fixed-fee
CRT - Cathode Ray Tube

D

DAF - Department of the Air Force
db - Decibel
DCO - Development Contract Office
- Development Contract Officer
DEI - Development Engineering Inspection
DEW - Distant Early Warning
DME - Distance Measuring Equipment
DN - Department of the Navy
DOD - Department of Defense
DOVAP - DOppler Velocity And Position
DPO - Development Planning Objective
DRL/UT - Defense Research Laboratory/The University of Texas; Austin, Texas

E

EAFB - Edwards Air Force Base; Edwards, California
- Eglin Air Force Base; Valparaiso, Florida
EAPD - Eastern Air Procurement District
E & ST - Employment and Suitability Test
ECCM - Electronic Counter-Countermeasure (s)
ECL - Equipment Component List
ECM - Electronic Countermeasure (s)
ECP - Engineering Change Proposal
EDPC - Electronic Data Processing Center
EDPS - Electronic Data Processing System
EMA - Electronic Missile Acquisition
EML - Equipment Modification List
EPS - Emergency Power Supply
EWR - Early Warning Radar

F

FBM - Fleet Ballistic Missile
FCC - Federal Communications Commission
FCS - Federal Catalog System
FFAR - Forward-Firing Aerial Rocket
FM - Frequency Modulated
FSA - Federal Security Agency
FSE - Field Support Equipment
FSN - Federal Stock Number

G

GALCIT - Guggenheim Aeronautical Laboratory, California Institute of Technology; Pasadena, California
GAM - Guided Aircraft Missile
GAPA - Ground-to-Air Pilotless Aircraft
GAR - Guided Aircraft Rocket
GAT - Greenwich Apparent Time
GB - Glide Bomb
GBL - Government Bill of Lading
GC - Ground Control
- Grand Central Rocket Company; Redlands, California
GCA - Ground Controlled Approach
GCC - Ground Control Center
GCI - Ground Controlled Interception
GCR - Ground Controlled Radar
GCT - Greenwich Civil Time
GE Heavy Mil Elec - General Electric Heavy Military Electronics Division; Syracuse, New York
GE Light Mil Elec - General Electric Light Military Electronics Division; Philadelphia, Pennsylvania
GF - Aviation Guided Missile
GFAE - Government-Furnished Airborne Equipment
GFE - Government Furnished Equipment
GFM - Government Furnished Material
GFP - Government Furnished Property
GHA - Greenwich Hour Angle
GM - Guided Missile
GMT - Greenwich Mean Time
GSE - Ground Support Equipment
G.Z. - Ground Zero

H

HADC - Holloman Air Development Center; Alamogordo, New Mexico
HAPO - Hanford Atomic Products Operation; Operated by General Electric for the Atomic Energy Commission; Hanford, Washington
HE - High Explosive
HGE - Ground Handling Equipment
HIG Gyro - Hermetically-sealed Integrating Gyroscope
HVAP - High Velocity Armor-Piercing rocket
HVAR - High Velocity Aircraft Rocket

I

I & M - Installation and Maintenance
IAS - Institute of Aeronautical Sciences
IBDA - Indirect Bomb Damage Assessment
ICAO - International Civil Aeronautics Organization
ICBM - Intercontinental Ballistic Missile
ICFATCMUTAL - 'Individual is cleared for access to classified material up to and including'
ICUS - Inside Continental United States
ICW - Interrupted Continuous Wave
IF - Intermediate Frequency
IFF - Identification, friend or foe
IFRB - International Frequency Registration Board
IGOR - Intercept Ground Optical Recorders
IM - Interceptor Missile
IMO - International Meteorological Organization
IOC - Initial Operational Capability
IRBM - Intermediate Range Ballistic Missile
IRE - Institute of Radio Engineers
IRT - Interrogator-Response-Transponder

J

JCS - Joint Chiefs of Staff
JLC - Joint Logistics Committee
JOC - Joint Operations Center
JPL - Jet Proplusion Laboratory; Pasadena, California
JRDB - Joint Research and Development Board
JSPC - Joint Strategic Plans Group

K

KAPL - Knolls Atomic Power Laboratory; Operated by General Electric for the Atomic Energy Commission; Schenectady, New York

L

lox - Liquid Oxygen
LRPGD - Long Range Proving Ground Division

M

MAD AEC - Military Application Division of the Atomic Energy Commission

MADW - Military Air Defense Warning Net
mae - Mean Absolute Error
MAL - Materiel Allowance List
MEAL - Master Equipment Allowance List
meru - milli-earth rate unit
MB - Munitions Board
MEW - Microwave Early Warning Radar
MHE - Materiels Handling Equipment
MIRAN - MIssile RANging
MIL STD - Military Standard
MOC - Master Operational Controller
MS - Margin of Safety
MSA - Mutual Security Agency
MSP - Mutual Security Program
mtbf - Mean-Time Between Failure
MTI - Moving Target Indicator
MWO - Modification Work Order

N

NAA - National Aeronautical Association
- North American Aviation Incorporated; Inglewood, California
NACA - National Advisory Committee for Aeronautics
NaDevCen - Naval Air Development Center
NAMTC - Naval Air Missile Test Center; Point Mugu, California
ND - Navy Department
NDRC - National Defense Research Committee
NEMA - National Electronic Manufacturing Association
NME - National Military Establishment
NOL - Naval Ordnance Laboratory; White Oak, Maryland
NOLC - Naval Ordnance Laboratory, Corona; Corona, California
NOTS - Naval Ordnance Test Station; China Lake, California
NPSH - Net Positive Suction Head
NR - Noise Ratio
NSA - National Security Agency
NSC - National Security Council
NSS - National Stockpile Site

O

OAL - Ordnance Aerophysics Laboratory; Convair; Daingerfield, Texas
OCLUS - Outside Continental United States
OJT - On-the-Job Training
ONI - Office of Naval Intelligence
ONR - Office of Naval Research
OpNav - Office of the Chief of Naval Operations
O Plan - Operation Plan
ORD - Operational Ready Date
Ordcit - Ordnance, California Institute of Technology; Pasadena, California
ORI - Operational Readiness Inspection
ORT - Operational Readiness Test
OSN - Office of the Secretary of the Navy
OSRD - Office of Scientific Research and Development
OSS - Office of Strategic Services
- Operational Storage Site
OST - Operational Suitability Testing
OSW - Office of the Secretary of War
OTU - Operational Training Unit
OWI - Office of War Information

P

PAM - Pulse Amplitude Modulation
Patrick AFB - Patrick Air Force Base; Cocoa, Florida
PCM - Pulse Code Modulation
PDA - Pump Drive Assembly
PDM - Pulse Duration Modulation
p.e. - Probable Error
PET - Production Environmental Testing
PGC - Proving Ground Command
P-I - Photogrammetric Instrumentation
PM - Pulse Modulation
PPI - Plan Position Indicator
- Present Position Indicator
PRF - Pulse Repetition Frequencies
PTM - Pulse Time Modulation
PWM - Pulse Width Modulation

Q

QA - Quality Assurance
QC - Quality Control
QOR - Qualitative Operational Requirement
QPRI - Qualitative Personnel Requirements Information

R

R & D - Research and Development
RACE - Rapid Automatic Checkout Equipment
RADC - Rome Air Development Center; Griffis Air Force Base; Rome, New York

RADCM - Radar Countermeasures and Deception
radl - Radiological
Radlab - Berkeley Radiation Laboratory
Radlwar - Radiological Warfare
RATO - Rocket Assisted Take Off
RCM - Radar Countermeasures
RDB - Research and Development Board
RDF - Radio direction-finder
RETMA - Radio, Electronics, and Television Manufacturers Association
RF - Radio Frequency
RFA - Requests for Alterations
RGZ - Recommended Ground Zero
RI - Radio Inertial (Guidance System)
Rosebud - A kind of airborne radar beacon used in radar control and IFF
ROTI - Recording Optical Tracking Instrument
RSO - Range Safety Officer
R/V - Re-entry Vehicle

S

SAB - Scientific Advisory Board
SAC - Strategic Air Command; Offut Air Force Base; Omaha, Nebraska
SAF - Secretary of the Air Force
SAGE - Semi-automatic Ground Environment
Sandia Base - The Sandia Corporation; Division of Western Electric; Albuquerque, New Mexico
SCEL - Department of the Army; Signal Corps Engineering Laboratories; Fort Monmouth, New Jersey
SENL - Standard Equipment Nomenclature List
SI - Shipping Instructions
SMART - Supersonic Military Air Research Track; Hurricane Mesa, Utah
SNL - Standard Nomenclature List
SNORT - Supersonic Naval Ordnance Research Track; Naval Ordnance Test Station; China Lake, California
S/N Ratio - Signal to Noise Ratio
SOFAR - SOund Fixing And Ranging
SONCM - Sonar Countermeasures and Deception
SOP - Standing Operating Procedure
SpecDevCen - Special Devices Center; Bureau of Aeronautics; Department of the Navy
SRI - Stanford Research Institute; Stanford, California
SSIP - Sub-System Integration Plan
SSM - Surface-to-Surface Missile
SUM - Surface-to-Underwater Missile
SWC - Special Weapons Command
SWEL - Special Weapons Equipment List
SWR - Standing Wave Ratio

T

TAC - Tactical Air Command
TACAN - TACtical Air Navigation
TAD - Target Area Designation
TAF - Tactical Air Force
TM - Tactical Missile
TMB - David Taylor Model Basin; Washington, D. C.
T/O - Table of Organization
TTAF - Technical Training Air Force; Gulfport, Mississippi
TTE - Tentative Table of Equipment
T/A - Table of Allowance

U

UAL - Unit Authorization List
UAM - Underwater-to-Air Missile
UEE - Unit Essential Equipment
UME - Unit Mission Equipment
UOC - Ultimate Operational Capability
UR - Unsatisfactory Report
USM - Underwater-to-Surface Missile
USNMTC - United States Naval Missile Test Center; Point Mugu, California

W

WADC - Wright Air Development Center; Wright Patterson Air Force Base; Dayton, Ohio
WDD - The Western Development Division, Air Research and Development Command; Los Angeles, California/New designation for WDD is BMD (Ballistic Missiles Division)/
WPAFB - Wright-Patterson Air Force Base; Dayton, Ohio
WR - War Reserve
WS - Weapon System
WSEG - Weapons Systems Evaluation Group

WSM - Weapons System Manager
WSPG - White Sands Proving Ground; Las Cruces, New Mexico
WSPO - Weapon System Project Office
WSSM - Weapon System Supply Manager

Z

Zebra Time - Greenwich Mean Time
Z.I. - Zone of Interior

Ablating Nose Cone

One which depends on controlled erosion of the nose cone (in ballistic missile applications) to accomplish reentry without performance degradation.

Abort (Aborted)

Discontinuance of test.

Angle of Fire

An indication of antenna direction.

Antenna, Helix

An antenna used where circular polarization is required.

Automatic Terrain Recognition And Navigation System (ATRAN)

A map matching system for missile navigation. One version uses a tape or film recording of terrain covered in the flight and previously obtained by reconnaisance. A continuous comparison of desired position with actual position is made to provide appropriate corrections.

BOA

Broad Ocean Area

Balance-Unbalance (Balun)

Precision-wound auto-transformer for adapting from balanced to unbalanced lines. Used to prevent mismatch losses.

Baro Fuze (Barometric Fuze)

A device similar to an aneroid-type altimeter used to perform certain program steps in the arming and detonation of an explosive device.

Beam Capture

In a radar beam riding guidance system, the act of placing the missile in the radar beam so as to provide coded guidance signals. (See Fig. 10.10, p. 405)

Burning, Rough

Severe pressure fluctuations frequently observed at the onset, but which can occur at any time, of burning, and at the combustion limits of ramjet or rocket.

CFAE

Contractor Furnished Aeronautical Equipment

CZR-1 Camera

Missile tracking equipment used to obtain primary trajectory data (launch to about 5000 ft).

Approximate accuracies (out to 2000 ft)

Position $\pm$ 3 ft

Velocity $\pm$ 14 fps

Camera speed is 30 frames/sec.

Cine-Theodolite

Missile tracking equipment used to obtain position data up to about 100,000 ft. 35 mm cameras record azimuth and elevation.

Approximate accuracies:

Distance 10 to 50 ft.

Angular 20 sec.

Circuit Diagram

A line drawing used in electrical and electronic theory and maintenance showing specific wire connections, and individual parts such as resistors, potentiometers, coils, and capacitors.

Combustion Chamber

That area within which burning of the fuel-oxidizer mixture occurs in any combustion engine. In rocket engines, the combustion chamber is the enclosed volume between the injector face and an imaginary plane across the throat of the nozzle.

Coordinates, Inertial Cartesian

Three mutually perpendicular coordinate axes (X,Y,Z), located in inertial space; X is positive to the east, Y is positive to the east, Y is positive to the north, and Z is positive up (altitude).

Coordinates, Spherical

The magnitude of the radius, and its angular displacement in azimuth and elevation from a line running east at the origin.

Coordinates, Test Range

The coordinates used to define the position of the missile while in flight. These are:

(a) Down Range: The great circle distance from the launch point to the projection of the position point onto the range plane.

(b) Cross Range: The great circle distance from the position point to its perpendicular projection of the range plane. (See Great Circle Distance)

Corona

A halo, usually electrical in nature. Astronomically, usually refers to the ion halo around the sun; in electricity, a silent discharge, very pale blue in color.

Coulmer Array (Antenna)

A planar antenna array consisting of non-resonant elements stacked vertical-

ly and horizontally with respect to each other. The result is both vertically and horizontally polarized waves to produce a high gain antenna.

ELectronic SkyScreen Equipment (ELSSE)

A missile-trajectory measuring system used to provide azimuth data. Telemetering transmitters or other airborne transponders may be used for a signal source. Usually used for range safety.

Exhaust Velocity, Effective

The effective exhaust velocity of a rocket engine is the average axial velocity of the jet stream leaving the exhaust nozzle.

Errors

(1) Systematic Error: A constant error or one that varies in a systematic manner throughout a missile test: e.g., instrument misalignment.
(2) Random Error: An error which varies in a random fashion during a missile test: e.g., instrument internal noise or film reading error.
(3) Absolute Error: An error expressed in dimensional numbers: e.g., a velocity error in ft/sec.
(4) Relative Error: An error relative to a quantity of the same dimension: e.g., a relative error of 1 part in 1000.

Factors

(1) Load Factor: The acceleration of a mass expressed in "G" units, where "G" represents the acceleration due to gravity.
(2) Material Factor: A factor of safety included because of uncertainty of material strength.
(3) Factor of Safety: The ratio, considered in design, of the strength of a structure to the maximum calculated operational load on the structure (limit load). (See also Factor of Safety)
(4) Ultimate Factor of Safety: The ratio of the ultimate strength of a structure to the limit load.
(5) Yield Factor of Safety: The ratio of the yield strength of a structure to the limit load.
(6) Ultimate Strength Load Factor: The load factor which shall cause the ultimate strength to be reached.
(7) Yield Strength Load Factor: The load factor which will cause the yield strength to be reached.

Failure Classes

(1) Early Failures: Those failures which occur early in the life of an equipment at a rate in excess of the rate to be expected due to chance. Failures due to inherent weakness built into the equipment during fabrication in excess of inherent design weaknesses.
(2) Chance Failures: Failures which occur at a constant rate following removal of early failures. Failures due to inherent weaknesses in the equipment or process design.
(3) Wearout Failures: Failures which occur late in the life of an equipment and ultimately are cause for failure of all equipment remaining. Failure due to weaknesses created in the equipment by its use.
(4) Catastrophic Failures: Failures which cause an equipment to become inoperative.

Failure Classes, Physical Cause

(1) Design Oversight: Condition correctable by changing design parameters and/or specified materials.
(2) Low Safety Factor: Specified use of materials at or near their strength limits.
(3) Excessive Variance: Use of materials or combinations of materials whose statistical variability is such that the equipment has a high probability of failure.
(4) Production Engineering: Use of manufacturing or assembly techniques which produce unsatisfactory deviations from prototype.
(5) Workmanship: Individual variations from specified or normal manufacturing or assembly techniques.
(6) Inspection: Failure to detect a defect when methods for detection are available or can be developed.
(7) Process Drift: Gradual shift or a processing technique to the point at which one or more parameters are intolerable.

(8) Handling and Storage: Subjection of an equipment to non-use conditions in excess of normal or specified conditions.
(9) Adjustment or checkout: Use of procedures or operating techniques for adjustment or checkout which causes failure of an equipment or its parts.

Failure Classes, Severity
(1) Abortive: One that judgement and experience indicate could result in catastrophic failure of the entire weapon system.
(2) Critical: One that judgement and experience indicate could result in failure of the entire weapon system other than catastrophic.
(3) Time Limit: One that judgement and experience indicate can become critical or abortive but which has been averted by replacement within a specified time. Time limit failures will only be classified by actual weapons system experience.
(4) Non-Critical: One that judgement and experience indicate will not cause failure of the entire weapon system.
(5) Associated: One which results from the failure of another interdependent equipment. A failure which judgement and experience indicate would not have occurred if failure of an associated equipment had not occurred.

Failure Terms
(1) Defect: Any physical property which precludes an equipment's conformance to a specified characteristic.
(2) Defective: (a) To contain one or more defects. (b) An equipment which contains one or more defects.
(3) Reject: An equipment which has been discovered to be defective and which cannot be made acceptable by further processing.
(4) Rework: An equipment which has been discovered to be defective and which can be made acceptable by further processing.
(5) Failure: (a) An equipment which contains no defects which adversely affect the function of the equipment upon completion of fabrication, but which becomes defective after completion; (b) An equipment which is found to be responsible for failure of equipment of which it is a part; (c) The event responsible for an equipment becoming a failure.
(6) Malfunction: Synonymous with failure.

Feedback, Structural
A low frequency oscillation of the airframe structure, caused by feedback (through the airframe or the air) of the structural and rigid body vibrations to servo mechanisms located within the airframe, causing actuation of the aircraft controls in response to the vibrations.

Feedback Tests, Structural
A test to determine the flight control system stability characteristics during structural feedback vibration.

Firings
(1) Blow Down: Simulated missile thrust engine system operation with non-combustible fuel combinations.
(2) Mock Firing: A test that simulates a complete flight test operation with the exception of firing.
(3) Hot Firing: Missile thrust engine operation with combustible fuel.
(4) Captive Tests: Missile tests which are conducted with the engine firing and the missile secured to the test stand, to evaluate and develop the missile system.
(5) Flight-Readiness Firing Test: Short duration hot firing test of a flight missile secured to a test stand at test field. This test is run to checkout the missile for flight status. The engines are started and brought up to full thrust.
(6) Flight Firing: Hot firing of missile engine during flight.

Flame Deflector
A large structure beneath the thrust mount that deflects exhaust gases away from the firing complex.

Flame Shield
Sandwich type rigid insulation that protects the attachment frames, thrust

mount, and load struts from heat during firing.

Flight Test

Tests conducted to determine system operational characteristics, reliability, and sequencing while the missile is in flight.

Flight Test, Certification

A propulsion test to prove the capability of the component to function properly in a minimal flight environment (temperature and vibration). Less stringent than for flight qualification tests.

Flight Test, Qualification

A propulsion component test to prove the capability of the component to function properly under stringent flight and ground environmental conditions for use in the flight article.

Flow, Inviscid

Fluid flow neglecting the effects of viscosity.

Flutter, Panel

Dynamic instability of a panel subjected to airflow parallel to its equilibrium midplane.

Forward Scatter

Extended range radio-wave propagation attained by forward scatter from the ionosphere.

Frequency, Weathercock

The frequency of the characteristic motion of a missile airframe as it returns to its steady state condition after a disturbance has produced an unbalanced moment.

General Operational Requirement (GOR)

The initial requirements established by the Military Services for a weapon system. These represent the boundary conditions for the preliminary design.

Gimbal

A mechanical frame containing two mutually perpendicular intersecting axes of rotation.

Great Circle Distance

The great circle distance between two points, defined as the shortest distance along the surface of the earth (sea level) connecting two points. The great circle distance between two points not at sea level is taken as the great circle distance between the vertical projections of the two points upon the sea level surface.

Gyroscope, Cryogenic

A gyroscope employing spinning electrons at near absolute zero instead of the conventional spinning flywheel. (Development Stage)

Hold Parameter

A test situation, circumstance, or condition which requires that a testing sequence not proceed until the hold condition is resolved.

Impact Point, Nominal

A fixed location in each impact area, chosen for planning purposes in connection with instrumentation systems. This point when chosen will remain fixed throughout the test program.

Impedance

The complex ratio of a force-like quantity (force, pressure, voltage, temperature or electric field strength) to a related velocity-like quantity (velocity, volume velocity, current, heat flow, or magnetic field strength). The terms and definitions under the term "impedance" pertain to single-frequency quantities in the steady state, and to systems whose properties are independent of the magnitudes of these quantities. These quantities can be represented mathematically by complex exponential functions of time. Under these conditions the factors involving time cancel out in the ratios called for, leaving complex numbers independent of time. Solutions based on complex exponential functions under these conditions give the solution for real sinusoidal oscillations. Because of the similarity of electrical, mechanical and acoustical transmission theory, the same terminology is used in the three cases. Where confusion is likely to occur, the proper term should be prefixed to the general term: e.g., acoustic transfer impedance; i.e., while acoustics is a branch of mechanics, it is found convenient to distinguish an acoustic system from a mechanical one whenever elastic wave motion is an essential feature. While a strict application of the impedance concept implies the restrictions given above, it is common practice to extend

the term "impedance" to situations involving nonsinusoidal quantities or nonlinear systems. Such extensions should be accompanied by an explanatory statement. (See Impedance, Acoustic; Impedance, Electrical; Impedance, Mechanical)

Impulse, Effective

The effective impulse is equal, by specification definition, to that portion of the thrust-versus-duration curve between the 90 percent-of-rated-thrust ordinates on a plot made of the complete firing of a rocket engine.

Injection Pressure

The pressure difference between the total pressure at the propellant outlet orifice and the pressure in the combustion chamber.

Instantaneous Impact Prediction (IIP)

The prediction of the anticipated impact point of a missile or reentry body by means of a ground-based computer using appropriate tracking data. Used for range safety.

Intermediate Focal Length Tracking Telescope (IFLTT)

35 mm and 75 mm cameras with 40" and 80" lenses for high speed tracking of missiles during early portions of the trajectory.

Jetavators

Control devices used in jet exhausts to provide a steering or rolling moment. A partial extension of the nozzle which is turned to deflect the jet. Such a system is usually very nonlinear.

Kill Parameter

A test situation, circumstance, or condition which requires that a test run be terminated immediately.

Launch Pad

In general, this is a 100 by 200 foot reinforced concrete slab with underground access tunnels or trenches to the blockhouse. In a typical tunnel is found power monitor and firing circuit cables, and emergency power equipment.

Logistic Protection

In a guided missile system, that provision that insures the missile against functional degradation due to all the environmental factors encountered from the manufacturer's plant to operational expenditure. This environmental phase may be divided into two categories:

(a) Transportation: Any movement, vertical or horizontal, of the missile.

(b) Storage: The time during which the missile is not being moved, and may be of short or extended duration.

Luneberg Lens

An artificial type of lens employed at microwave frequencies for focusing to attain high gain.

Mils (Missile Impact Location System)

A splash net system using hydrophones.

MUF

Maximum Usable Frequency

Magnetohydrodynamics

The study of ionized gases and their control by electrical and magnetive fields.

Main Bang

In a radar set, the term applied to the transmitted pulse.

Malf-Out

Malfunction or failure of component.

Mean Mixture Ratio

The mean mixture ratio is equal to the average oxidizer flow rate, divided by the average fuel flow rate, within the 90 percent-of-rated thrust ordinates of a curve made of a complete firing on a rocket engine or gas generator.

Metric Data

Those data which are obtained primarily for measurement purposes and from which a quantitative evaluation of missile performance may be made. Metric film is the film exposed for metric data purposes.

Microwave Amplification by Stimulated Emission of Radiation (MASER):(Molecular Oscillator, Versitrons, Quantum-Mechanical Amplifiers)

Devices made with gases or solids in which atoms or molecules can be raised to a high energy level at which they are unstable. A signal will cause them to radiate excess energy at a specific wavelength. Energy emitted greatly exceeds incoming signal. Gaseous masses produce uniform and precise oscillations.

Model Types

(1) Research Model: Includes any one or all of the following: breadboard model and development model.

(a) Breadboard Model: An assembly of parts and/or components to test the feasibility of a proposed design. Usually electrical or electronic.

(b) Development Model: A model used to develop and/or perfect the proposed design of a component, subsystem or system. Usually non-electrical.

(c) Mathematical Model: A mathematical representation of a missile and/or its system and components which can be used to predict performance.

(2) Prototype Preproduction Model: A model suitable for evaluation of mechanical and electrical form, design and performance. It approaches final mechanical and electrical form, employs approved parts, or reasonable equivalent, and is representative of final equipment.

(3) Production Model: This is equipment in its final mechanical and electrical form, of final production design and made by production tools, jigs, fixtures, and methods.

Multiple Hop

A radio transmission path, characterized by more than one reflection from the ionosphere and the earth. Multiple path transmission can result from different depths of ionospheric penetration as well as from varying frequency of transmissions.

Off Load

In propellant loading, it is sometimes necessary to adjust gross weight or center of gravity. This is accomplished by off loading.

Paschen's Law

The sparking potential of a gas is a function only of the product of the sparking distance and the gas pressure. (Min. sparking potential for air $\simeq$ 340 v)

Permeability

The ratio of magnetic induction (B) to magnetizing force (H). Maximum permeability is the slope of the B-H curve at its steepest point. Dynamic or a-c permeability is the slope of a line drawn through the tips of an a-c hysteresis loop (B_{Tip}/H_{Tip}).

Pitch Programmer

A device used to provide initial pitch or tiltover guidance to a vertically launched missile to put it "on target". The device may be airborne or ground-based with a radio link.

Power Supply, Static

A non-rotating alternating current power supply.

Propellant, Trapped

At engine shutdown, that mass of propellant below the interface of the propellant pump and feed system.

Q

A figure of merit for effective heat absorbing capacity per pound of a material (Btu/lb). Essentially the specific heat when considering only the solid state.

Quality Assurance

With the greatly increasing proportion of inspectors in precision factories, the inspection organizations have become so large that their reporting to top management does not alone assure that a "Quality Control" group (under the same top supervision) will impartially patrol their own organization.

In some cases, management has considered the inspection as a function alalogous to production, and established an organizationally separate group reporting to top (corporate) management, known as Quality Assurance, for the purpose of impartially "auditing" the quality function: e.g., the A.E.C. has contracted to a Sandia "Quality Assurance Department" the responsibility to police all

inspection practices in their area; even Sandia's own inspection department.

The area generating the Quality Assurance action will vary with the organizational breakdown concerned, but the basic distinction is that it refers to an organizational concept of quality enforcement; not to any specific improved inspection technique. From the contractor's point of view, the Air Force inspectors are a Quality Assurance group.

Quick Reaction Capability (QRC)

Ability to develop a rapid counterattack.

Remanence

The residual induction B_r when the magnetizing field is reduced to zero after saturation.

Roll Capture

Missile flight paths which do not require initial roll stabilization may require a period of time to roll-stabilize. Proper roll orientation, which permits guidance signal decoding, is termed roll capture.

Single Hop

Refers to the relatively long range spanned by a radio wave departing from its transmitter at a small angle to the horizontal. This type of wave penetrates only a relatively short distance into the ionosphere before it is reflected to the earth's surface.

There is a definite maximum range that can be spanned by "single hop" transmission. This is the distance covered by a ray departing horizontally. It is about 1500 miles in the case of E-layer transmissions.

Skip Zone (Skip Distance)

The area within the range of a radio transmitting station in which that station's signals are heard poorly or not at all—affected area determined by operating frequency of station and height of ionized layers in ionosphere.

Skyscreen, Optical

Vertical wire system used to determine "safe trajectory" limits. A pair oriented at 90° are used to provide elevation and azimuth limits. Range limit is about 2000 ft.

Strouhal Number

A dimensionless parameter relating frequency of shedding of vortices to the wind velocity and characteristic dimension.

$$\text{Strouhal Number} - \frac{\omega d}{2 \pi V}$$

where d = dia. of missile or structure, ft

ω = frequency of vortex shedding, rad/sec

V = velocity of air flow, ft/sec.

TBM

Tactical Ballistic Missile; Theater Ballistic Missile

Tilt Table

A table of accurate orientation with respect to the local gravity vector. Used to test accelerometers.

Trajectory, Ballistic

A missile trajectory which follows a symmetrical path from launch to impact. The powered flight portion is followed by a "pure" ballistic trajectory to reentry.

Trajectory, Glide

A long-range missile trajectory in which the initial powered flight is followed by a reentry glide at optimum lift/drag ratio in the upper portions of the atmosphere. The glide portion may be accompanied by maneuvers to avoid counter-measures. (See Vehicle, Glide)

Trajectory Phases

(1) Launch Phase: Normally that portion of the test from launch to booster burnout, in the case of aerodynamic missiles; or from launch to motor burnout, in the case of ballistic missiles. (Note: this definition may vary from missile to missile and must be defined for each missile.)

(2) Mid-Course Phase: From end of launch phase to beginning of terminal phase.

(3) Terminal Phase: That portion of the test from initiation of terminal dive or recovery, in the case of aerodynamic missiles, or from reentry (approx. 100,000 ft altitude), in the case of ballistic missiles, to termination of test.

Trajectory, Powered Flight
In a ballistic, glide or skip missile trajectory, that part which includes flight while under power from booster, sustainer or vernier engines. During this period azimuth, elevation and velocity adjustments are made in terms of intended target coordinates.

Trajectory, Skip
A long-range missile trajectory in which the initial powered flight is followed by a reentry skip and glide path using the upper portion of the atmosphere to support the missile aerodynamically on successive ballistic type reentries. (See Vehicle, Skip)

Trajectory, Terminal
The portion of the trajectory between reentry and impact. Reentry occurs at an altitude of approximately 250,000 ft.

Vehicle, Glide
A hypersonic vehicle with a power boost similar to a long-range ballistic missile but with lifting surfaces to provide an optimum lift/drag reentry in the sensible atmosphere. Contrast with Skip Vehicle. (See Trajectory, Glide)

Vehicle, Skip
A hypersonic vehicle with a power boost similar to a long-range ballistic missile, but with lifting surfaces to proreentry control. Contrast with Glide Vehicle. (See Trajectory, Skip)

Zener Voltage
(1) The field required to excite the Zener current, of the order of 1 volt per unit cell or 10^7 volts/cm.
(2) The voltage associated with that portion of the reverse volt-ampere characteristic of a semi-conductor wherein the voltage remains substantially constant over an appreciable range of current values.

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ABOUT THE EDITOR

GRAYSON MERRILL, Captain, USN, (ret.) has long been a pioneer in guided missile technology. A graduate of the U. S. Naval Academy and a qualified naval aviator, he returned to Annapolis in 1940 to study radio engineering at the U. S. Naval Postgraduate School. After the outbreak of World War II he took a leading part in the Navy's guided missile program, personally conceiving and guiding the development of the GORGON, the first jet propelled guided missile to fly in the United States; the LARK anti-aircraft guided missile; and the submarine-launched LOON, predecessor to the REGULUS. His foresight led to the establishment of the Naval Air Missile Test Center at Point Mugu, California, which he organized in 1946 as its first Director of Tests. In later years he served in the Bureau of Aeronautics' Guided Missile Division, directing such developments as SPARROW and REGULUS and in the Bureau of Ordnance as Technical Director of the JUPITER Ballistics Missile Project. He is now Director of Engineering, Fairchild Guided Missile Division, Fairchild Engine and Airplane Corporation.

ABOUT THE AUTHOR

C. W. BESSERER is a member of the Senior Staff, Space Technology Laboratories, The Ramo-Wooldridge Corporation. A graduate of the University of Texas, he later became Assistant Professor of Mechanical Engineering there. He has been actively engaged in the field of guided missiles since 1945, first as a member of the Principal Staff and Supervisor in Charge of Engineering at the Applied Physics Laboratory of the Johns Hopkins University, then as Assistant Chief Project Engineer, Missile Division, Bendix Aviation Corporation, and currently is associated with the Air Force's Inter Continental Ballistic Missile program. He is the author of the Mechanics and Physics Section of the *Tool Engineer's Handbook*, a co-author of *Aerodynamics, Propulsion, Structures and Design Practice*, and the holder of several government patents in missile ordnance. He is a Registered Professional Engineer in the State of Texas, a member of Pi Tau Sigma, a member of The American Rocket Society, and an officer of the Machine Design Division of the American Society of Mechanical Engineers.

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